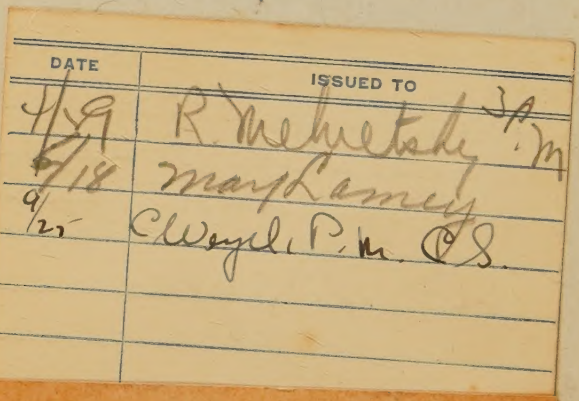

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NEW YORK AND CHICAGO

AMERICAN SCIENCE SERIES

THE ELEMENTS OF GEOGRAPHY

BY

ROLLIN D. SALISBURY

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AND

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STATE TEACHERS COLLEGE OF SAN FRANCISCO

NEW YORK

HENRY HOLT AND COMPANY

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The Lakeside Press
R. R. DONNELLEY & SONS COMPANY
CHICAGO

PREFACE

COURSES in physical geography have been given for years, with great success where conditions have been favorable, and with indifferent success in some other places. Recently there has been a widespread demand for a more general course in geography, particularly where physiography has not been thought wholly satisfactory, a course which should treat physiographic processes and features briefly, and develop at greater length the relations of earth, air, and water to life, and especially to human affairs. This book is designed to serve as the basis for such a course. The authors have sought to give the student (1) an understanding of the elements of geography, (2) an interest in the subject, and especially (3) training in clear thinking. Many of the facts of geography will be forgotten presently by most students, while the power and habit of thinking clearly will be of service in meeting every problem of later years. Indeed, the book has been written with the belief that the chief object in geography teaching should be preparation for citizenship. No subject is better adapted to this purpose. This conviction has led the authors to emphasize certain points now or likely soon to be of national importance, as, for example, the need of conserving the natural resources of the country.

All rational work in general geography must be founded on physiography, and this fact has determined the organization of the material of this book. The principles developed have been applied at greatest length to the United States, because this country is of most interest and importance to American students. Furthermore, space forbade the application of these principles in detail to other countries.

The illustrations should be regarded by the teacher as vital. They are intended to serve as the basis for classroom discussions and quizzes, and should be studied and interpreted as carefully as the text itself. The answers to most of the questions which appear at the ends of the chapters and elsewhere are not to be found in the text, but may be reasoned out by the student if he has read the text with understanding. The questions may be used for written exercises and

tests, as well as for class room discussion. In the opinion of the authors, these questions are by no means the least important part of the book, and their careful use is recommended to every teacher who uses the text.

References are given at the ends of the chapters or sections, to assist the teacher in supplementing the work of the text. The extent to which these references can be used to advantage will, of course, depend upon the advancement of the pupils, the time at their disposal, and the library facilities at command. By their extended use, the text may be made the basis of courses more advanced than those of secondary schools.

The maps at the end of the book afford the student the means of locating most of the places and features mentioned in the text.

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ELEMENTS OF GEOGRAPHY

CHAPTER I

THE NATURE OF GEOGRAPHY

Ancient and modern geography. Geography has been studied since ancient times, for people always have wanted to know about the earth on which they lived; but the conception of geography has changed greatly as years have gone by. In olden times geography was regarded as a description of the earth. It included an account of the countries into which the earth is divided, their physical features, such as rivers, mountains, and plains, and their inhabitants and products. Modern geography is concerned especially with the effects of physical features, such as land forms, water, and climate, on living things. Hence geography is defined now as the study of the earth in its relations to life.

Divisions of geography. It is clear that there are two main parts to the study of geography: (1) The physical features of the earth (land, water, air) which affect life; and (2) the ways in which different forms of life respond to their physical surroundings.

Various groups of physical phenomena may be the subjects of special study. Thus the phenomena of the atmosphere are considered in *meteorology* and *climatology;* those of the waters in *oceanography* and *hydrography;* and those of the lands in *physiography*, as some would define that term. Similarly, earth relations to life may be studied with special reference to plants (*plant-* or *phyto-geography*), to animals (*animal-* or *zoö-geography*), or to man (*human-* or *anthropo-geography*).

Relations to other subjects. The study of these different phases of geography brings it into contact with many other sciences. The form, size, and motions of the earth are matters of *astronomy* as well as geography; the origin and characteristics of land forms

and the distribution of useful minerals are matters of *geology* as well as geography; the effects of physical conditions on plant and animal life are phases of *botany* and *zoology* as well as geography; the distribution of mankind, man's subdivision of the earth into political units, and many other matters, relate geography closely to *history;* and man's present activities, influenced by geographic conditions, are factors of *political economy.*

Importance of human geography. Since man is the most important form of life, most interest attaches to the study of the earth in its relations to him. Human activities are so many and varied, and are influenced in so many ways by physical conditions, that special study often is made of related effects. Thus *economic geography* traces the influence of natural factors in the production of things useful to man. The relations of land forms, soil, and climate to the raising of crops is an example. *Commercial geography* considers the influence of natural factors in the transportation and exchange of various commodities, as the trade in tropical fruits between warm regions and those too cold to raise them. *Historical geography* is concerned with the influence of physical conditions on past events. *Political geography* traces the influences of location, topography, climate, and natural resources on the development of different countries. The effect of position may be seen in the fact that the Netherlands, at the mouth of the Rhine, rose to great commercial importance, in contrast with agricultural Denmark on the one side, and industrial Belgium on the other.

The basis of other studies. Since geography shows the many ways in which the earth is related to the life of man, it is important as the basis of many other studies.

Geography is especially important in connection with the study of *history,* for in all ages the conditions under which people lived have influenced their occupations, their stage of development, and their relations to the rest of the world. The better geography is understood, therefore, the easier it is to understand the significance of historical events. The Jews in Palestine never developed seafaring habits because the nearest coast was devoid of good harbors, while their neighbors, the Phœnicians, on a more favorable coast, were the first good sailors, and for many years were influential in Mediterranean districts outside their own country. Russia has striven for more than two centuries to secure satisfactory seacoasts, and as a result has been led to great territorial expansion and into

wars with her neighbors. Most of the incidents which led up to the war with Japan were connected with this expansion. Great Britain, protected from invasion by her insular position, was able at an early date to use her natural resources to great advantage, and became the leading manufacturing and commercial nation of the world. In our country, slavery developed most extensively in the South, mainly because the conditions of field labor there favored it more than in the North. These few examples suggest the close connection between geography and some important facts and phases of history.

Geography is related no less intimately to *present events*. The distribution of people over the face of the earth, the manner in which they live, and their grouping in countries and cities always bear some relation to earth conditions. Many old cities, like Venice, were located where defense against invasion was easy. Most recent cities have been located with respect to natural advantages for manufacturing or commerce. Food, dress, shelter, occupations, industries, products, trade, and many other facts and conditions of life are influenced by physical surroundings. Deserts are characterized by scanty vegetation, mostly unlike that of other regions. Desert animals also are few because plants are few and water scarce, and they differ from those of well-watered regions, partly because of the difference in the plants on which they must feed. Since man depends on plants and animals for food, clothing, and shelter, desert populations are small.

Tropical natives wear little clothing and eat little meat, largely because bodily temperatures are maintained easily without either. They engage but little in commerce, because their wants are few. The people of middle latitudes, on the other hand, must adapt themselves, in the matter of food, clothing, and shelter, to extremes of heat and cold. Their wants are therefore many and varied. Complex industries and world commerce are needed to satisfy them. The United States is the greatest producer of foodstuffs, because of the great extent of favorable surface, soil, and climate—resources which a progressive people have used to advantage. Several countries of western Europe have advantages for extensive manufacturing, such as supplies of coal near good seaports; but they cannot produce all the raw materials needed for their factories, nor all the food for their factory workers. Hence large quantities of raw materials and food, like cotton and copper, flour and meat, are exported annually from the United States to these European countries. Great Britain,

being a small but highly developed country, requiring many things from abroad, has been led to abolish nearly all import duties. The United States, on the other hand, is so nearly self-sufficient in most necessities of life, that it has been led to maintain rather high import duties, with a view to insuring the home producer an advantage in supplying local markets. Not all parts of the United States, however, are agreed on the subject of import duties (tariff), for the country is so large that its several parts differ in geographic conditions, and hence in leading interests. Many Minnesota farmers, for example, oppose reciprocity with Canada because they fear lower prices for their grain and live stock if Canadian grain and cattle come in free. Most of the people of Massachusetts, on the contrary, interested primarily in manufacturing, favor such a treaty because it may open a better market for their manufactured wares and give them cheaper food-stuffs. Thus some of our current politics is, at bottom, a matter of sectional geography.

An understanding of the larger relations between physical conditions and life in general is necessary to an understanding of the effects of the physical surroundings of man on his interests and activities. This in turn helps one to understand the affairs of the world, and therefore is important to good citizenship.

CHAPTER II

EARTH RELATIONS

The Solar System

Early conceptions of the relations of the earth. For thousands of years men believed that the earth was the center of the universe. They thought that the sun, moon, and other heavenly bodies actually revolved around it (as they seem to), and that these bodies were created and maintained to give light and heat to the inhabitants of the earth. In the sixteenth century it was proved that the sun, moon, and stars *appear* to revolve about the earth because the latter rotates on an axis, and that, far from being the central and largest part of the universe, the earth is merely one of the smallest of a great family of bodies. Beyond the great system to which the earth belongs, there are many thousands of stars, each of which may be compared to our sun, though many of them are vastly larger.

Members of solar system. The solar system includes the sun and all the bodies which revolve about it (Fig. 1). There are eight

Fig. 1. Diagram of the solar system. The size of the bodies is exaggerated enormously as compared to that of the orbits.

planets, of which the earth is one. To us, all the planets except our own appear as stars, but in their motions they differ from other stars. Commencing with the nearest to the sun, the planets are, in order: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. All but Mercury and Venus have *satellites* corresponding to our moon. Saturn has nine of them.

Besides the planets and their satellites, the solar system includes numerous (more than 400) *asteroids*, bodies much smaller than the planets, intermediate in position between Mars and Jupiter, and those *comets* which revolve about the sun. Comets and asteroids have little influence on the earth.

The sun is a vast sphere (more than 1,000,000 times as large as the earth) and very hot. From the sun the earth receives nearly all its heat and light. The other planets shine only by reflected sunlight.

The planets. The planets are all of similar form, and probably of similar composition. All rotate on axes, and move in nearly circular paths about the sun in the same direction, but they are strikingly unlike in some respects. Jupiter, the largest, has a diameter more than ten times as long as that of the earth, while Mercury, the smallest planet, has a diameter only about one-third that of the earth. The innermost planet revolves about the sun in 88 days, the outermost in 165 years. The former is about two-fifths as far from the sun as the earth is, while the latter is over 30 times as distant. The shortest rotation period of a planet is less than 10 hours, while that of Venus is nearly 225 days. From the standpoint of life, the earth is the most favored of the planets in all these respects. Indeed, the conditions of heat and light would prevent the existence of such life as we know on most of the other planets.

The origin of the earth. The history of the earth's origin is not known with certainty. Until the close of the last century, Laplace's *nebular hypothesis* of the solar system had been accepted with little question. This hypothesis assumed that the sun, together with all other members of the solar system, were once parts of a glowing-hot gaseous mass, called a *nebula*. It assumed further, that this enormous volume of gas was rotating and cooling. Rotation caused its equatorial part to bulge, cooling caused the whole to shrink, and shrinking quickened rotation. The result, so the theory runs, was that the main body of the rotating mass shrank away from the equatorial bulge, leaving it outside as a ring, somewhat like the rings which surround Saturn now. Once left outside, the ring was assumed to have broken up, and its materials to have come together into a sphere, making a planet. The eight planets were assumed to have been formed from eight successive rings, the outermost being the oldest. The sun is the part of the original mass not made into planets. Some of the planets in turn developed rings in the same way as the central body, and these rings became satellites.

According to this hypothesis, the earth, at its birth, was a huge ring of hot gas, from which the central body, including what is now the sun and the two planets nearest to it, shrank away. The substance of this ring became a spheroidal mass, which, as it rotated, gave off a ring that became the moon. By cooling, the gases of the early earth condensed into liquid, and still later, according to the hypothesis, the cooler outer part became solid. In applying the

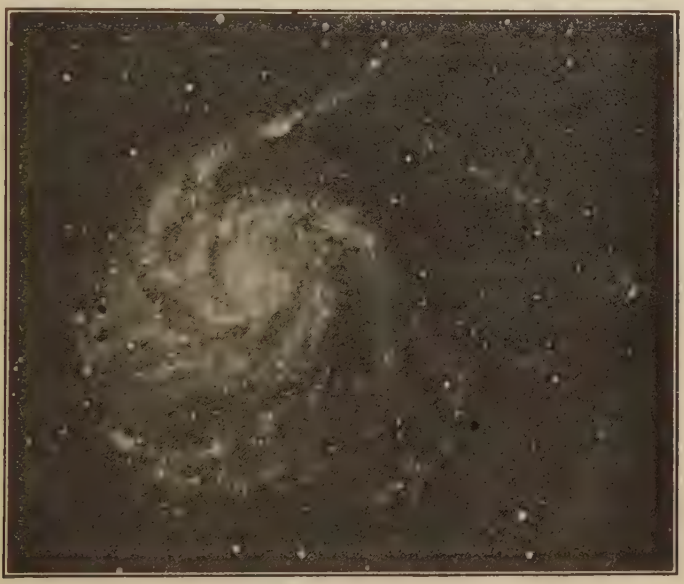

Fig. 2. Spiral nebula. (Photographed at Yerkes Observatory.)

hypothesis to the earth, it was long assumed that the interior of the earth was still liquid; but this is not a necessary part of the nebular hypothesis.

In recent years strong arguments have been brought against this hypothesis, — arguments so strong that, in its original simple form at least, the nebular hypothesis can be held no longer.

Another hypothesis, known as the *planetesimal hypothesis*, has been suggested in its place. This hypothesis assumes that the beginning of the solar system was a *spiral nebula*, similar to the commonest type of existing nebulæ (Fig. 2). This nebula is assumed

to have consisted, like nebulæ now, of a central portion, with two long curved arms. Like existing spiral nebulæ, too, it is assumed to have been composed of multitudes of small solid bodies, not hot, together with numerous particles of gas. Each small body is thought to have revolved about the center of gravity of the whole. The development of the solar system out of this nebula consisted in the gathering of these small, scattered bodies into a few; namely, the sun, the planets and their satellites, and the asteroids. According to this hypothesis, the earth was never gaseous, never liquid, and perhaps never very hot on the outside, but grew to its present size by the accumulation of multitudes of small bodies. Its interior heat was developed during its growth, the central parts being squeezed into smaller space by the weight of all matter added to the outside. This process produced heat. The amount of heat developed in this way would be quite enough to explain the temperature of the earth's interior.

The nebular hypothesis assumed that the atmosphere was once enormously more extensive than now, that it has become less and less, and that it will in time disappear altogether. The planetesimal hypothesis assumes that the earth, in the early stages of its growth, had little or no atmosphere, that the atmosphere has grown with the rest of the earth, and that there is no reason to suppose that it is becoming less now, or that it will become less in the future.

No serious arguments have been brought against the planetesimal hypothesis, and it is, at the present time, the most acceptable hypothesis of the earth's origin.

The Earth as a Planet

Form. The form of the earth is very much like that of a sphere, but since it is not exactly a sphere, it is called a *spheroid*. The form has been determined in various ways: (1) Ships have sailed around it. This proves that it is everywhere bounded by curved surfaces, but it does not prove that it is a sphere or even a spheroid, for it would be possible to sail around it if it had the shape of an egg. (2) When a vessel goes to sea, its lower part disappears first, and when a vessel approaches land, its highest part is seen first from the land. By people on the vessel, the highest lands are seen first, and the low ones later; the spires and chimneys of buildings appear before the roofs, and the roofs before the lower parts. Like (1) above, these

facts show only that the earth has a curved surface. But from whatever port vessels start, and in whatever direction they sail, objects on land disappear at about the same rate. This means that *the curvature of the surface is nearly the same in all directions.* A body whose curvature is the same in all directions is a sphere, and a body whose curvature is nearly the same in all directions is nearly a sphere. This is the condition of the earth. (3) Again, the earth sometimes gets between the sun and the moon. It then casts a shadow on the moon (making an eclipse), and this shadow always appears to be circular. In these and other ways it is known that the form of the earth does not depart greatly from that of a sphere. (4) That the earth is *not exactly round*, however, is shown in various ways. For example, a body weighs slightly more in high latitudes than in low latitudes. This means that it is nearer the center of the earth in the high latitudes than in the low; or, in other words, that the earth is not a true sphere. (5) Again, as one travels in any direction, new stars appear above the horizon ahead, and rise in the sky as the traveler advances, while those which were low in the sky behind, sink and disappear below the horizon. This indicates that the surface of the earth is curved. The distance of the stars is so great that, were the surface of the earth flat, a given star would appear to be at the same elevation above the horizon at all places on the earth. Were the surface equally curved everywhere, the same distance would have to be traveled in all parts of the earth in order to change the altitude of stars by a given amount. It has been found, however, that for a given amount of change, one must travel farther in high latitudes than near the equator. Like the variation in the weight of a body, this shows that the earth is a spheroid, rather than a true sphere.

Origin and consequences of the earth's form. There is no reason for thinking that the form of the earth was ever very different from its present form. Even if it had been very irregular originally, this form could not have persisted long, for the rocks of the deep interior would have yielded under the very unequal pressures that would have existed beneath the high places and the low ones. The higher parts of the surface would have sunk, and the lower parts would have been forced outward, until a roundish form was developed. Again, as the surface rocks decayed and broke up, rains and streams would have washed the loose material from the high places to the low ones, helping to produce a spherical shape.

The spheroidal form of the earth facilitates travel and transportation. It aids commerce in another important way. The attraction of the earth causes bodies to have weight. Because the earth is nearly round, gravity is nearly equal everywhere upon its surface, and, as we have already seen, the weight of a given object is therefore nearly constant. If the weight of things varied greatly from place to place, this variation would interfere seriously with trade between different parts of the world.

Size. The circumference of the earth is nearly 25,000 miles, and its diameter nearly 8,000 miles. Since the earth is not a perfect sphere, its various diameters and circumferences are not exactly equal. Its longest diameter is 7,926.5 miles and its shortest nearly 27 miles less (7,899.7 miles).

The area of the earth's surface is nearly 197,000,000 square miles. Were the earth as large as some other planets, intercourse between the opposite sides would be much more difficult than now. Thus, the proportions of Jupiter applied to the earth would mean a width of 30,000 miles for the continent of North America, and an expanse of water between the United States and Europe which only the fastest steamships could cross in less than six weeks. The amount of fuel required for such long ocean voyages would seriously restrict intercourse between different parts of the world. As it is, modern means of transportation make it possible for every nation to draw supplies from the most remote regions.

Motions

The earth has two principal motions: (1) It rotates on its shortest diameter, called its *axis*, and (2) it revolves around the sun. The axis is an imaginary line, and its ends are the *poles*. The circumference midway between the poles is the *equator*.

Rotation. The rotation of the earth from west to east gives us day and night, for one side of the earth and then the other is turned toward the sun during each rotation. The time of rotation, about 24 hours, determines the length of a day (day and night). The length of the period of rotation can be measured by means of the stars (How?). The period of rotation thus measured is called the *sidereal day* (Latin *sidus*=a star). The time between two successive noons is the *apparent solar day*. As the earth rotates on its axis, it also moves forward in its path around the sun, faster when nearer the sun, and slower when farther away from it. One result of this

forward motion of the earth is to make solar days a little longer than sidereal days (Why?). Solar days vary slightly in length (Why?). The *mean solar day* has the average length of the apparent solar days.

Human activities are in general adjusted to the turning of the earth, the succession of daylight and darkness affording convenient intervals for work and rest. In those parts of the earth where the intervals of light and of darkness are many days (instead of hours), this habit of regularity of work and rest is less general. During the long period of light, the hunting people of Greenland, for example, cease their work or seek rest only when fatigue overtakes them. During the long night they have no regular work or exercise, and are much less vigorous than in the period of light. The long night of polar regions is very trying to the health and strength of people accustomed to a period of light each day.

The period of rotation furnishes also a natural unit for measuring time. Astronomers use the sidereal day as a time unit, but the mean solar day is the one commonly used. Again, the rising and setting of the sun, due to the earth's rotation, give us a simple system of directions.

Revolution. The earth revolves about the sun in a little more than 365 days, and the period of revolution fixes the length of the year. The path of the earth around the sun is its *orbit.* The orbit of the earth is not a circle, but a curve called an *ellipse* (Fig. 3), and the

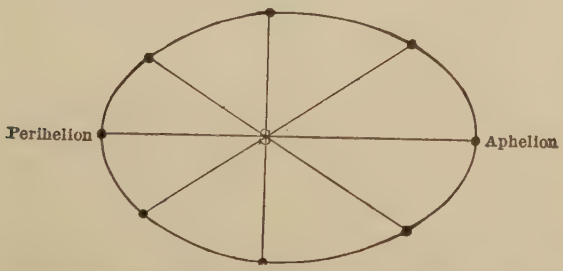

Fig. 3. The orbit of the earth is an ellipse, with the sun in one of the foci.

distance of the earth from the sun varies from time to time. When the earth is nearest the sun (*perihelion*), the distance between them is about 3,000,000 miles less than when they are farthest apart (*aphelion*). The earth is nearest (about 91,500,000 miles) the sun in the early part of the winter of the northern hemisphere (about

January 1st), and farthest (about 94,500,000 miles) from it early in the summer.

The motion of the earth through space during its revolution about the sun is at the rate of about 600,000,000 miles a year, or more than 1,100 miles each minute.

The earth's axis is inclined toward the plane of its orbit about 23½ degrees (Fig. 4). This position of the axis, together with

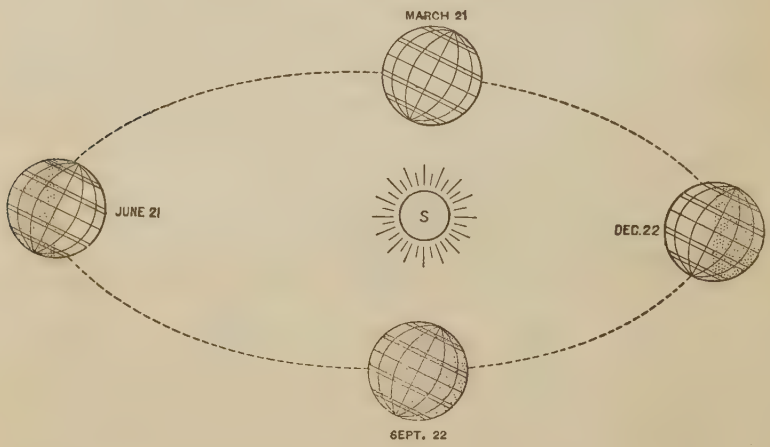

Fig. 4. Diagram showing the position of the earth with reference to the sun at the solstices and equinoxes, and the inclination of its axis.

the motions of the earth, has much to do with the distribution of the heat and light received from the sun, with the changes in the length of day (daylight) and night, and with the seasons.

Latitude, Longitude, and Time

Latitude. The *equator* has been defined as the circle about the earth midway between the poles. Circles parallel to the equator are *parallels*. The number of parallels which might be drawn is very large, though only a few are represented on maps. The length of parallels varies greatly, those near the equator being longer, and those near the poles shorter. The north and south lines that pass from pole to pole on the earth's surface are *meridians*. All meridians come together at each pole.

A few meridians and parallels appear in Fig. 5, which shows

the earth in two positions. The left-hand part of the figure shows the half of each parallel represented and the whole of each meridian. The right-hand part shows the relation of parallels to the North Pole. The distance between the equator and either pole is divided

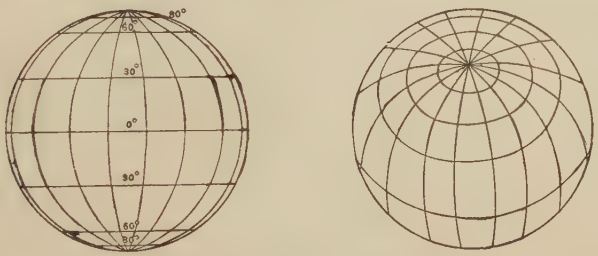

Fig. 5. Parallels and meridians.

into 90 parts, called *degrees* (written 90°). Each degree is divided into 60 parts, called *minutes* (60′). Each minute is divided into 60 parts, called *seconds* (60″). Distance north or south of the equator may therefore be determined from a globe or map by means of parallels. The system of parallels and meridians is made possible by the form of the earth and its rotation on its axis.

Distance north or south of the equator is called *latitude*. *North latitude* is north of the equator, and *south latitude* is south of it. The degrees, minutes, etc., are numbered from the equator toward the poles. The latitude of the equator is 0°. Latitude 1° N. is one degree north of the equator, and latitude 90° N. is at the North Pole. Latitude 1° S. is one degree south of the equator, and latitude 90° S. is at the South Pole. If the latitude of a place is 40° 40′ 40″ N., its distance and its direction from the equator are accurately known; but its position on the parallel of 40° 40′ 40″ is not known, for that parallel runs around the earth.

Longitude. Position on a parallel is indicated by means of the meridians which cross it. The number of possible meridians is very great, but, as in the case of parallels, only a few are commonly shown on maps. One meridian, that passing through Greenwich, England, where the British Royal Observatory was established in 1675, is usually chosen as the meridian from which distances east and west are reckoned (Fig. 6). This meridian is the meridian of 0°, and is sometimes called the *prime meridian*. Distance east or west of this

meridian is known as *longitude*. Places east of longitude 0° are in *east longitude*, and those west of it are in *west longitude*. East and west longitude respectively are regarded as extending 180° from the meridian of 0°; that is, half-way around the earth.

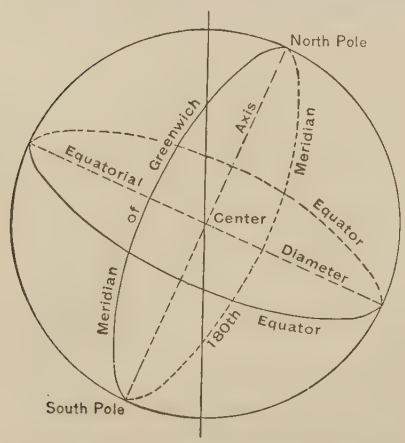

Fig. 6. Diagram showing the position of the axis of the earth, the poles, the equator, the meridian of Greenwich, and the meridian of 180°.

The position of a place on the earth's surface may be fixed exactly by means of meridians and parallels. If a place is in longitude 30° E., its distance east of the meridian 0° is known. If at the same time it is in latitude 30° N., it must be on the parallel of 30° N. where it is crossed by the meridian of 30° E. So convenient and accurate is this method of locating places and reckoning distance that parallels and meridians are used in many places as boundaries between states, counties, and townships. They have great value, too, in determining positions at sea. The modern science of navigation, so important to commerce, may almost be said to have had its foundation in the discovery of these earth relations.

The poles are the only places which have latitude but no longitude. Since all meridians come together at the poles, the poles cannot be said to lie either east or west of the meridian of Greenwich. At the North Pole the only direction is south, and at the South Pole the only direction is north.

Longitude and time. There is a definite relation between longitude and time. Since the earth turns through 360° in 24 hours, it turns 15° in one hour, and 15′ of longitude in one minute of time. The sun therefore rises one hour earlier at a place in longitude 0° than in a place in the same latitude in longitude 15° W., and one hour later than at a place in the same latitude in longitude 15° E. Similarly, noon comes an hour earlier in longitude 0° than in longitude 15° W., and an hour later than in longitude 15° E. All places on a given meridian have noon at the same time and midnight at the same

time, and such places are said to have *the same time;* but places on different meridians have different times. St. Louis is about 15° farther west than Philadelphia, and Denver is about 15° west of St. Louis. When it is noon at Philadelphia it is about eleven o'clock at St. Louis and ten at Denver. When it is one o'clock at Philadelphia it is noon at St. Louis and eleven o'clock at Denver, and when it is noon at Denver it is one o'clock at St. Louis and two at Philadelphia.

The variations of time with changes of longitude become apparent when long journeys are made either east or west. Thus a watch which

Fig. 7. Map showing standard time belts of the United States, Dec., 1912.

has the correct time in New York has not the correct time when it is carried to Chicago. To avoid the difficulties of time-keeping growing out of travel, the railroads of the United States have adopted a system of *standard time.* Under this system the country is divided into north-south belts of convenient width (Fig. 7), and in each belt all railways use the same time. The railway time in adjacent belts differs by one hour. By this system, clocks and watches do not show correct *local* time except on one meridian of each belt. The irregular boundaries of the belts are due to the adoption of the nearest important railway points as the places for changing time on east and west journeys.

Lengths of degrees. The length of a degree of longitude, as measured on the surface of the earth, is the $\frac{1}{360}$ part of a parallel. Since the parallels are very much shorter near the poles than near the equator, the length of a degree of longitude is less in high than in low latitudes. At the poles, where the length of the parallel becomes zero, the length of a degree of longitude also becomes zero. At the equator, the length of a degree of longitude is a little more than 69 (69.16) miles.

The most important result of variation in the lengths of degrees of longitude is found in the routes followed by vessels on long voyages east and west. The shortest route (*the Great Circle route*) between two points lying in about the same latitude, as San Francisco and Yokohama, is not along the parallel of 36° N., but is a route which takes the vessel several degrees north of 36° in the mid-Pacific. This can be seen readily on a globe. Another result appears when we attempt to show the curved surface of the earth on a flat map (p. 25).

Degrees of latitude are measured on meridians. They also vary in length. The length of a degree of latitude is about 68¾ miles in India, while in Sweden, the most northerly place where a degree has been measured, it is 69¼ miles. All measurements which have been made show that the length of a degree of latitude, measured on the earth's surface, increases as the poles are approached. At the poles it is calculated that it must be about 69⅜ miles. In the United States, the average length is about 69 miles. The increase of length of the degree toward the poles means that the earth is flattened there.

Inclination of Axis and its Effects

The sun's rays illuminate one-half of the earth all the time. The border of the illuminated half is called the *circle of illumination* (Fig. 8). All places on one side of the circle of illumination have day, while all places on the other side have night. If the axis about which the earth rotates were perpendicular to the plane in which the earth revolves about the sun, the circle of illumination would always pass through the poles. Under these conditions, half of the equator and half of every parallel of latitude would be illuminated all the time, as in Fig. 8. If the half of each parallel were always illuminated, the days and nights would be equal everywhere, for it takes just as long for a place at *A* (Fig. 8) to move to *B* (six hours,

half of a twelve-hour day) as for it to move from B to A' (half of a twelve-hour night). Since days and nights are not equal at all seasons in most parts of the earth, it proves that the axis on which the earth rotates is not perpendicular to the plane of its orbit.

Again, if the earth rotated on an axis perpendicular to the plane of its orbit, the sun would always be equally high at any given place at the same hour of the day. But this is not the case. In the United States, for example, the sun is much higher above the horizon at noon in summer than in winter. The same is true in all latitudes similar to those of the United States.

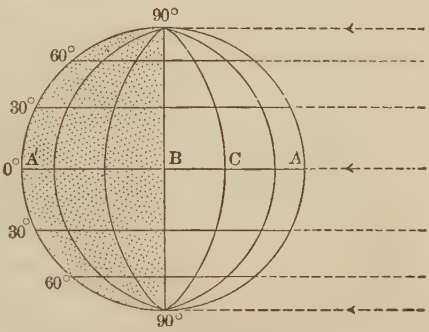

Fig. 8. Diagram to illustrate the fact that half of the earth is lighted by the sun at any one time. The parallel lines at the right show the direction of the sun's rays. The part of the earth not shaded is lighted by the sun; the other half is in darkness. The line between the illuminated half and the half which is not illuminated is the *circle of illumination*. This diagram represents conditions at the time of an equinox.

This variation of the angle at which the sun's rays strike the same place at different times, as well as the unequal lengths of days and nights in most places, is the result of the inclination of the axis on which the earth rotates as it revolves around the sun (Fig. 4). The position of the axis is constant throughout the year. The effect of the inclination of the axis is illustrated by Fig. 4, which represents the earth in four positions in its orbit. In the position marked March 21st, the half of each parallel (the half toward the reader) is illuminated. At this time, therefore, days and nights are equal everywhere. In the position marked June 21st, more than half (the part not shaded) of every parallel of the northern hemisphere is illuminated, and there the days are more than 12 hours long and the nights correspondingly less. In the southern hemisphere the nights are longer than the days. In the third position, September 22d, the days and nights are again equal everywhere, for the circle of illumination divides every parallel into two equal parts. In the figure, the lighted part is away from the reader. In the fourth position, December 22d, more than half of each parallel in the southern hemisphere is in the light, and there the days are longer than the nights, while

in the northern hemisphere the nights are longer than the days. Twice during the year, therefore, on March 21st and September 22d, the days and nights are equal everywhere. These times are known as the *equinoxes*. The equinox in March is the *vernal equinox;* that in September is the *autumnal equinox*.

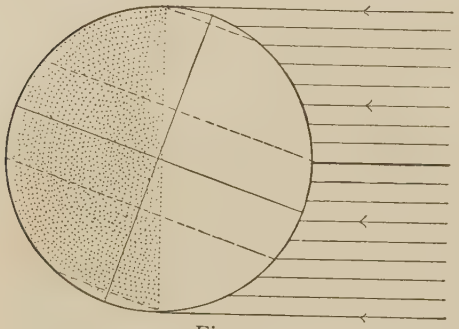

Fig. 9.

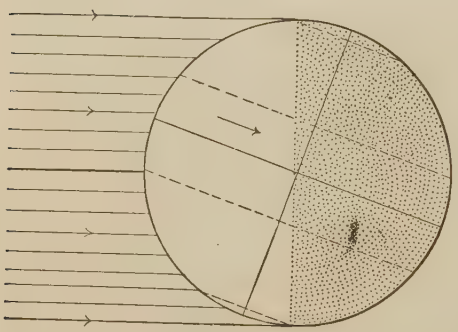

Fig. 10.

Fig. 9. Diagram illustrating the effect of inclination of the earth's axis on the length of day and night. In the figure, more than half of every parallel of the northern hemisphere is illuminated. The days in the northern hemisphere are therefore more than twelve hours long, since the half of each parallel is the measure of 180° of longitude, and 180° of longitude corresponds to twelve hours of time. Similarly less than half of every parallel of the southern hemisphere is illuminated, and the days are therefore less than twelve hours long.

Fig. 10. The relation of the earth to the sun's rays at a time six months later than that represented in Fig. 9. The conditions of day and night in the hemispheres are reversed.

When the earth is in the relation to the sun shown in the position marked June 21st, Fig. 4, the days are longest in the northern hemisphere, the sun is highest in the heavens at noon, and its rays fall perpendicularly on the surface of the earth farther north (23° 27′+) than at any other time. This is the *summer solstice* (Fig. 9). The *winter solstice* occurs six months later, when the sun's rays strike the earth vertically 23½° (nearly) south of the equator (Fig. 10), and when the days of the southern hemisphere are longest and those of the northern shortest. Figs. 9 and 10 also show that the *days and nights are always equal at the equator*, since the equator is always bisected by the circle of illumination. Days and nights are not always equal in any other latitude, unless at the poles,

where there is one day (or period) of six months of light, and one night (or period) of six months of darkness.

The relative duration of daylight and darkness, and the angle at which the sun's rays strike the earth, are the chief causes of changes of seasons. Thus at the equator, where the hours of day and night are always equal, and the sun's rays nearly vertical at all times of the year, seasons change but little, while toward the poles, say in Lat. 60°, where days and nights are very unequal most of the time, seasons are very much more extreme.

It will be seen, therefore, that most of our methods of reckoning years, seasons, days, distances and positions, weights, and directions depend on the various earth relations.

Apparent motion of the sun. The effect of the inclination of the axis of the earth is *to make the sun appear to move north and south* once during each revolution of the earth about the sun. That is, the revolution of the earth about the sun while it rotates on an inclined axis, makes the sun appear to move from a place where its rays are vertical 23½° (nearly) north of the equator (direction *S*, Fig. 11), to a place where they are vertical 23½° (nearly) south of the equator (direction *W*), and back again, in one year. The result, so far as the earth is concerned, is as if the sun moved from *S*, which corresponds to the time of the summer solstice, to *Sp & A*, which corresponds to the time of the autumn equinox, then to *W*, which corresponds to the time of the winter solstice, then back again to *Sp & A*, which corresponds to the spring equinox, and finally to *S*, while the earth is making one circuit about the sun.

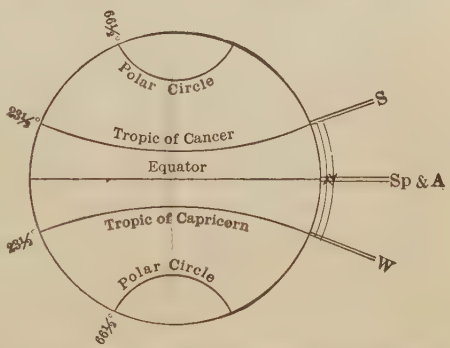

Fig. 11. Diagram illustrating the apparent motion of the sun.

When the sun is vertical at points north of the equator, the days are longer than the nights in the northern hemisphere, and the sun's rays strike the surface in the northern hemisphere more nearly vertically than they do in the southern hemisphere. The greater number

of hours of sunshine and the more nearly vertical rays explain the warmth of our summer, even though the earth is then farthest from the sun. In high latitudes, as in western Canada, the long period of sunlight (16 to 18 hours) is an important factor in the successful cultivation of crops, in spite of the short summer. When the sun is vertical at the equator, days and nights are equal everywhere, and when the sun is vertical south of the equator, days are longer than nights in the southern hemisphere, and the sun's rays are more nearly vertical there than in the northern hemisphere.

The northernmost parallel where the sun's rays are ever vertical is called the *tropic of Cancer*. The corresponding southernmost parallel is the *tropic of Capricorn*. The tropics are nearly $23\frac{1}{2}°$ ($23° 27'+$) from the equator, because the axis of the earth is inclined by that amount toward the plane of its orbit. The sun is vertical at the tropic of Cancer at the time of the summer solstice, and at the tropic of Capricorn at the time of the winter solstice. The parallels just touched by the circle of illumination at the time of the solstices are the *polar circles*. They are as far from the poles as the tropics are from the equator. They are therefore in latitude about $66\frac{1}{2}°$. The one in north latitude is the *Arctic circle*, and the one in south latitude is the *Antarctic circle*.

Within the polar circles the differences of the seasons are chiefly a matter of daylight and darkness. Between the tropics there are no seasons like those of the United States. Hence it is only between the polar circles and the tropics that there are four seasons of the year, to be called truly spring, summer, autumn, and winter.

Fig. 12. The world according to Hecatæus, 500 B. C. Shaded areas = water.

Progress of Knowledge of the Earth

The lands bordering the Mediterranean Sea were the first center from which effective geographical exploration was undertaken. Very ancient civilizations grew up in the rich valleys of the Euphrates, Ganges, and various Chinese rivers, but the explorations carried on from those centers added little to the knowledge of the earth. The ancient Greeks thought the world was a flat disc, bordered by an ocean river (Fig. 12).

The spherical shape of the earth was first proved by Aristotle in the fourth century B. C., and its size was first determined approximately in the next century by Eratosthenes, another Greek philosopher. During the fourth century B. C., Grecian sailors explored the western coast of Europe and discovered Great Britain, and Alexander the Great added much to the previous knowledge of Asia as far east as India.

Fig. 13. The known world according to Ptolemy, 150 A. D. Shaded areas = land.

During most of the Middle Ages little progress was made. Indeed, what was known of the world by Ptolemy in the second century A. D. (Fig. 13) represented almost the sum total of geographic knowledge to the middle of the thirteenth century. The book of Marco Polo (1298), describing his travels through Asia and the neighboring islands, furnished Europe with much of its early information concerning the East; but the influence of this great work was not felt at once. The printing press had not been invented, geography was clogged by tradition, and much of the account appeared to be a collection of romantic tales rather than of facts. Later, the views of no less an explorer than Columbus were influenced greatly by the work of Marco Polo.

From early times there was an important trade between Europe and the spice-bearing lands of southern and eastern Asia; but this trade added little to knowledge of eastern geography, for the goods commonly changed hands many times at the trading cities along the caravan routes. In the fifteenth century, when the demand for eastern goods was stronger than ever before, the trade was reduced greatly (1) through the Turkish conquest of the regions crossed by the northern trade routes to the shores of the Mediterranean and the Black seas, and (2) through the heavy taxes levied by Egyptian rulers on goods coming through that country. These things encouraged the search for a sea route to the East, and resulted in the discovery of the route around Africa to India by Vasco da Gama (1498) and in the discovery of America by Columbus (1492). These discoveries

changed the front of Europe from the Mediterranean to the Atlantic coast, and began a new period in history. The continued attempt of Spain to find a western route to the spice lands led to the first circumnavigation of the globe by Magellan (1519–1521), an achievement which settled beyond doubt the question of the general form of the earth.

The coasts of North America and South America were explored during the sixteenth and seventeenth centuries, and most of the shore-line of Australia during the latter period. During these centuries, too, the commercial nations of western Europe founded colonies and trading posts in many parts of the world. With the growth of colonies and the improvement of navigation, commerce became world-wide, and the oceans came to be highways connecting the continents, rather than barriers separating them. Much of interior North America was explored in the eighteenth century, while Africa and Australia were opened up during the nineteenth.

During late years, knowledge of the earth's surface has been extended rapidly, the latest advances being the reaching of the North Pole by Commander Peary in 1909, and the South Pole by Captain Amundsen in December, 1911. Much remains to be learned about the earth. The largest unexplored areas are those in polar regions, but there are little known areas in each of the continents except Europe. Only relatively small regions have been studied in detail by modern methods.

Maps and Map Reading

What is known of the earth's surface may be represented in various ways,— by globes, models, and maps. Globes have the great advantage of showing without distortion the distribution of land and sea, and other large surface features. It is not practicable, however, to make them large enough to show minor features, and, even apart from this, they are not suited to all purposes. Models, or relief maps, reproduce on a small scale the unevenness of the earth's surface. In order that the elevations may stand out clearly, their height is exaggerated greatly on most models, which are likely, therefore, to give false impressions.

Map projections. The necessity of representing part or all of the earth on a flat surface led very early to the making of crude maps (Fig. 12). It is, of course, impossible to show the rounded surface of the earth

on a flat surface without exaggerating or reducing certain parts, so that each of the many methods (*projections*) devised from time to time for representing the meridians and parallels of a globe on a plane surface, involves more or less distortion.

Almost all sailing charts and many maps of the entire world

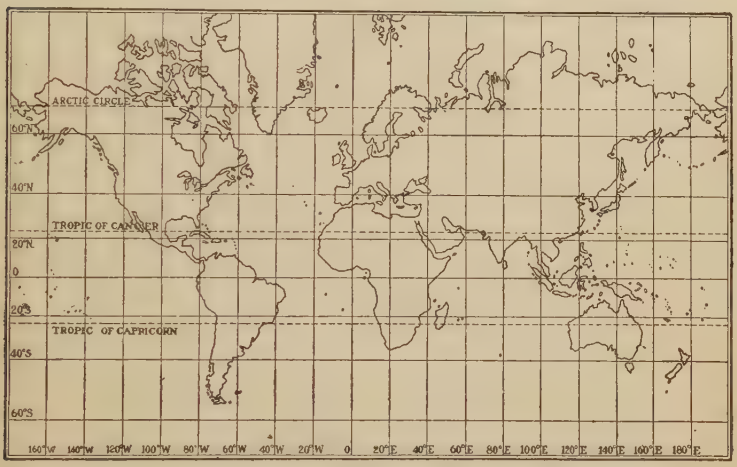

Fig. 14. Map on Mercator's projection.

are made on *Mercator's projection* (Fig. 14), named for the inventor. The principle involved in this projection may be understood by imagining a cylinder to be placed over a globe, as shown in Fig. 15. Next let straight lines be drawn from the center of the globe through various points on its parallels and meridians, and projected until they touch the cylinder. When the cylinder is cut down one side and opened out flat, there is a network of parallels and meridians, the former horizontal lines, the latter vertical. Features of any kind may now be put in

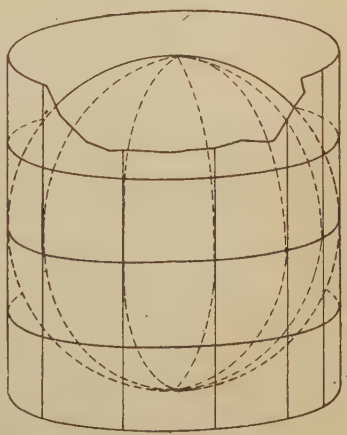

Fig. 15. Diagram to illustrate the principle of the Mercator projection.

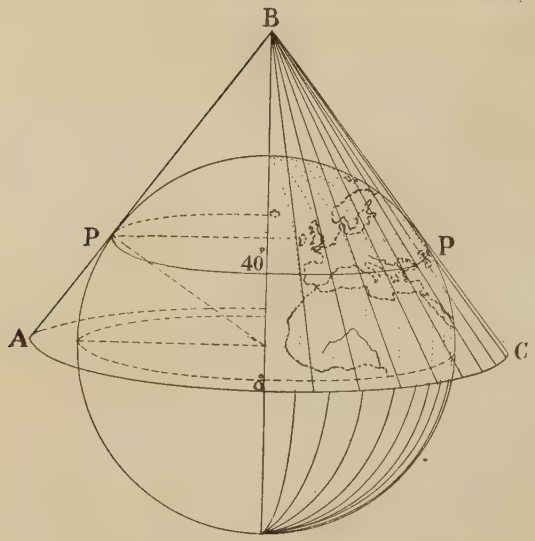

Fig. 16. Diagram to illustrate the principle of the conical projection. Cone ABC imposed upon sphere, touching it at PP.

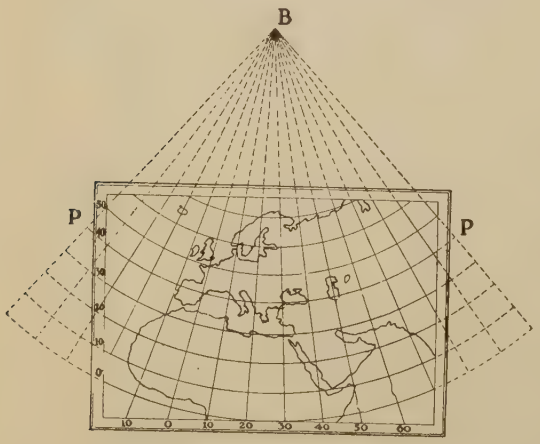

Fig. 17. Portion of surface of cone spread out, representing map. PP the parallel where the cone coincided with the sphere.

according to their known latitude and longitude. A map on Mercator's projection is accurate at the equator, but exaggerates areas more and more as the poles are approached. Thus Greenland (Fig. 14) appears to be about half as large as North America on a Mercator's map, while in reality it is less than one-fifteenth as large.

Figs. 16 and 17 show a portion of Europe on the *conical projection*, and also the way in which such a map is made. Imagine straight lines drawn from the center of the globe (Fig. 16) through numerous points on its parallels and meridians, and extended until they intersect the cone, which is so placed as to touch that parallel on the globe which runs through the center of the district to be

mapped. When the cone is cut open from the apex and flattened out (Fig. 17), the parallels are arcs of concentric circles, while the meridians are radiating straight lines. Some form of this projection is generally used for mapping individual countries. It involves comparatively little distortion. In practice, maps on these and many other projections are constructed by mathematical means, without the use of a globe.

Fig. 18. Map representing relief by hachures. (U. S. Geol. Surv.)

Representation of relief on maps. The surface of the land is uneven, and it is a matter of importance, in many cases, to show the unevennesses (*relief*) on maps. This is done in various ways. One method is by shading,— different colors or shades representing different elevations (see maps at end of book). Another method is by *hachures* (Fig. 18) — lines drawn in the direction in which the land slopes. Where slopes are steep, the lines are made short and heavy; where gentle, longer and lighter. Such maps give only a general idea of the form of the land.

Much more exact information may be had from *contour-line* maps. In order to read contour-line maps, it is necessary to know that *contours* are lines drawn on maps to express relief, and that any given line runs through points of the same elevation above sea-level. This will be understood readily by reference to Figs. 19 and 20. Fig. 19 shows a model of an ideal landscape viewed from above, on which lines have been drawn connecting places of equal elevation. In Fig. 20 the above lines are shown alone; this is a contour map of the region represented by the model. By comparison of the model and map it will be seen that where the slopes of the former are steep, the lines of the latter are close together, and *vice versa*. The vertical distance between two adjacent contour lines is the *contour interval*. The contour interval varies on different maps. In regions of low relief an interval of 10 or 20 feet is used generally; in mountainous areas an interval of 500 or more feet has to be used in some cases in order to avoid having the lines too close together to be read. In

the map of Fig. 20, the interval is 20 feet, the exact value of the 100 and 200 foot lines being indicated. By counting the lines it will be seen that the top of the hill to the left of the river is more than

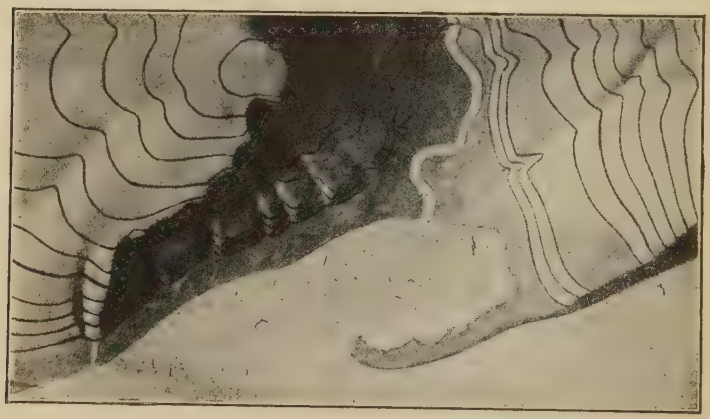

Fig. 19. Model of ideal landscape. (Model by H. Keeler.)

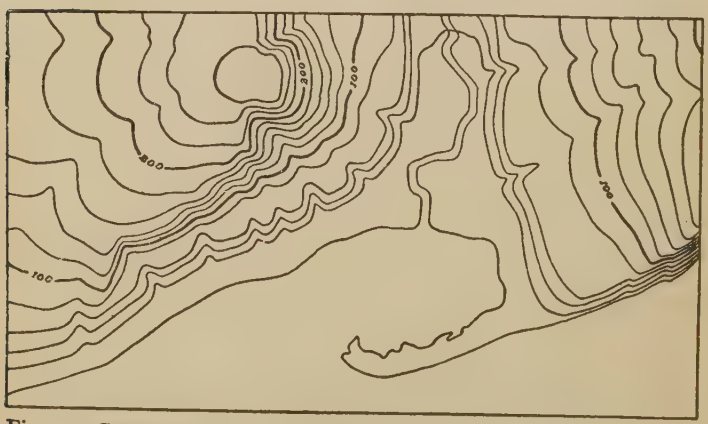

Fig. 20. Contour map of the area shown in Fig. 19. (U. S. Geol. Surv.)

260 feet above the level of the ocean in the foreground. It cannot be 280 feet high, however, for no 280 foot line is drawn. A comparison of the model and map will show also how valley depressions are shown by contours.

Scale of maps. The relation between distance on a map and actual distance on the surface of the earth is shown by the *scale.* It is sometimes expressed by a fraction. Thus $\frac{1}{62500}$ means that one inch on the map represents 62,500 inches (almost a mile) on the earth's surface. As expressed on most maps, the scale explains itself. It is important to note the scale of every map studied, in order to understand the space relations involved.

Terrestrial Magnetism

The earth is a great magnet, and, like the small magnets with which we are familiar, has two poles. One of these poles is called the *North Magnetic Pole* and the other the *South Magnetic Pole.* One end of the compass needle points toward one of these poles, and the other toward the other. If we were to follow the directions pointed by the compass needle, we would be led to the North Magnetic Pole in the one case, and to the South Magnetic Pole in the other.

The magnetic poles are far from the geographic poles, the true north and south points, and they are not exactly opposite each other. Their positions appear to shift a little from year to year, but the change is not known to be great. The North Magnetic Pole is in latitude about 70° N., and in longitude 97° or 98° W., while the South Magnetic Pole is in latitude 72° 25′ S., and longitude 155° 16′ E.

Since one end of the magnetic needle points to the North Magnetic Pole, it follows that the compass does not indicate true north and south in many places. At points north of the North Magnetic Pole, the "north" end of the needle points in a southerly direction. At points east of the same pole, it points westward, and at points west, eastward. The departure of the needle from the true north and south is *magnetic declination.* A line connecting places of no declination is an *agonic line,* and lines connecting places of equal declination are *isogonic lines.*

Fig. 21 shows an agonic line in the United States running from Lake Superior to South Carolina. Along this line the compass needle points due north and south. At all places east of this line the needle points west of true north, and such places have *west declination.* All places west of the agonic line have *east declination.* In general, declination increases with increasing distance from the agonic line. At New York City the declination is about 10° W., and in Maine it is more than 20° W. at a maximum. At Chicago the declination is

about 3° E., at Denver about 13° E., at San Francisco about 16° E., and in the state of Washington more than 20° E.

It will be seen that it is necessary to know the magnetic declination of a region, if the compass is to be used there for determining directions accurately. The declination being known, the compass is of great value to travelers through forests and other tracts which have no roads or trails. The compass, too, is in constant use on the sea, where vessels are guided by it.

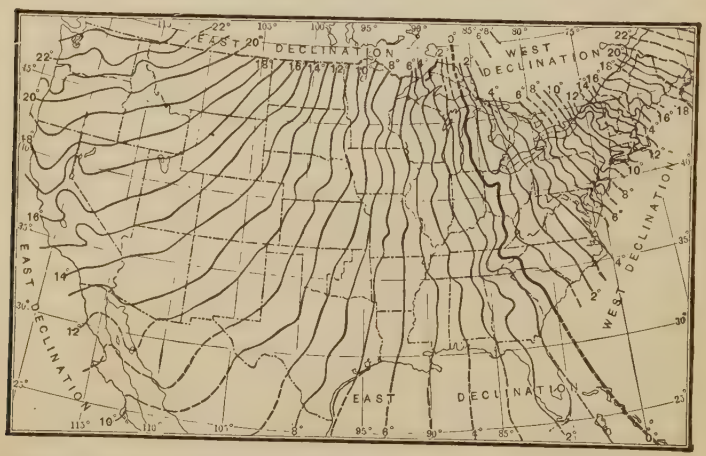

Fig. 21. Lines of equal magnetic declination for the United States, 1902. The heavy line is an *agonic line*, or line of no declination. (U. S. C. and G. Surv.)

The declination at a given place does not remain quite constant. The declination at Chicago, for example, has shifted more than 2° since 1820. With increased travel over the oceans, there is great need of accurate knowledge of compass declination and its variations. Hence vessels have been specially built and equipped to permit the greatest possible accuracy in making magnetic observations covering all the oceans of the world.

Questions

1. The horizon of a given observer increases as he rises. What does this prove concerning the shape of the earth's surface at that place? What additional inference could be made from the fact that as he ascends his horizon remains circular?

2. At places east of a given point the sun rises and sets before it does at that point. At places toward the west it rises and sets after it does at the station in question. What does this indicate as to the surface of the earth?

3. Why do the sun's rays never fall vertically in latitudes higher than 23½°?

4. Certain crops are said to mature faster in western Canada than farther south in the United States. Suggest a logical reason for this.

5. How would the seasons at Chicago (42° N.) be changed if the axis of the earth were inclined 45°, rotation remaining as now?

6. An ancient philosopher concluded, from observing the changes in the altitude of stars as he traveled, that the earth is not a very large sphere. What fact could have led him to this conclusion?

7. Two cities about 690 miles apart, on the same meridian, are located in latitude 42° N. and 32° N., respectively. From these facts determine approximately the circumference of the earth.

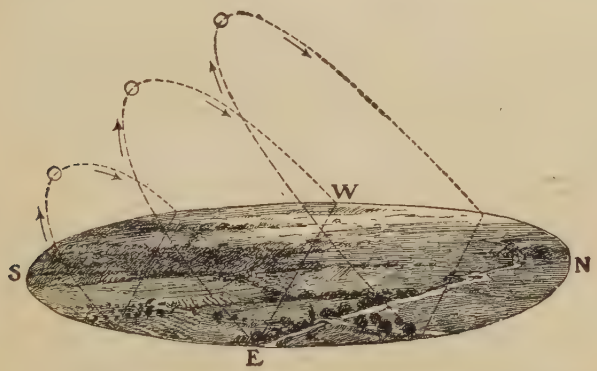

Fig. 22. Diagram showing the apparent daily course of the sun to an observer in northern United States, at different seasons.

8. Fig. 22 shows the apparent daily course of the sun to an observer in northern United States at different seasons. (1) Which of the paths indicated is followed by the sun in mid-winter? Spring? Mid-summer? Autumn? (2) What two reasons may be inferred from the diagram for the greater heat of summer? (3) Draw a similar diagram for 45° south.

9. Fig. 23 shows the apparent course of the sun to a given observer on a certain day. (1) In about what latitude is the observer? (2) What is the time of year? (3) What are the conditions of light and darkness at the same time in the corresponding latitude of the opposite hemisphere?

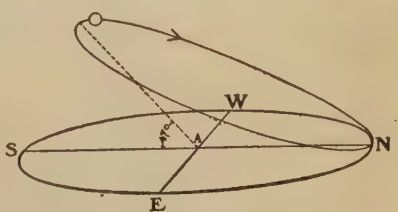

Fig. 23. Diagram showing the apparent course of the sun to an observer at A on a certain day.

10. What is the difference in longitude of two places having a difference in time of six and one-half hours?

11. What is the difference in solar time between New York City (74° W.) and Chicago (87° 36′ W.)?

12. The altitude of the sun at a given place at noon at the time of equinox is 50°. What is the latitude of the place?

13. In what latitudes is the altitude of the sun 20° at noon at the time of equinox?

14. In what latitudes has the sun a noon altitude of 30° at the time of the summer solstice?

15. What is the altitude of the sun at the equator at noon at the time of the summer solstice?

16. If you wished to go due north from San Francisco, how would you be guided by a compass?

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CHAPTER III

RELIEF FEATURES OF THE EARTH

The surface of the land is uneven. The lowest lands are below sea-level, and the highest point (Mt. Everest, in the Himalaya Mountains) is more than five and one-half miles above sea-level. The relief of the land surface is therefore not far from six miles. Compared with the diameter of the earth, even the loftiest mountains are slight elevations, for the height of Mt. Everest above the sea is equal to only $\frac{1}{1438}$ part of the polar diameter of the earth. On a globe 10 feet in diameter this would correspond to one-twelfth of an inch.

The sea bottom also is uneven, and its relief is a little greater than that of the land. Since the highest points of land are nearly six miles above the sea, and the lowest parts of the sea bottom about six miles below, *the relief of the surface of the solid part of the earth (lithosphere) is almost twelve miles*. If its surface were even, the water of the ocean would cover the whole earth to the depth of about 9,000 feet.

Relief Features of the First Order

Continents and ocean basins. The average elevation of the lands above sea-level is a little less than half a mile, while the average depth of the oceans is about two and one-half miles. The continents are therefore, on the average, nearly three miles above the bottoms of the ocean basins. It is fortunate that the general elevation of the land above sea-level is not greater than it is in middle and high latitudes. Were it equal to the average depth of the oceans, most of each continent would be too high and cold to support a dense population. *The continents and the ocean basins are relief features of the first order.*

The oceans have an area (143,000,000 square miles) nearly three times as great as that of the lands (54,000,000 square miles). The shallow water about the borders of the continents rests on surfaces (the *continental shelves;* Fig. 24) which are, in reality, parts of the continents. The continental shelves are but little below the lowlands of

many coasts, and they are far above the ocean bottoms. Since the seas not only fill the ocean basins, but spread over the continental shelves as well, their area is greater (by some 10,000,000 square miles) than that of the true ocean basins. The latter are a little more than twice as extensive as the continental plateaus. At the sea-ward edges

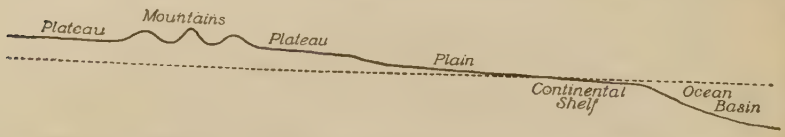

Fig. 24. Diagram to show the distinction between an elevated continental area and an ocean basin. The steep slope (much exaggerated) at the left of the ocean basin is the line of contact between the two, and is the real border of the continental area. The ocean covers the lower part of the continental tract, namely, the *continental shelf*. The diagram also shows the general relation between low mountains, such as the Appalachians, a low plateau, and a coastal plain. The continental shelf is a continuation of the coastal plain.

of the continental shelves there are rather steep slopes down to the ocean basins. Portions of the continental shelves may have been formed by the long-continued off-shore accumulation of sediments from the land; other parts are due to the submergence of former land areas; and still others are platforms resulting from the wearing back of the land by waves.

Many islands stand on the continental shelves, and represent higher areas whose lower surroundings are drowned. In many cases a slight elevation of the continental shelf, or a slight lowering of the sea, would join these islands to the mainland. Thus a change of only 300 feet would transform most of the area of the Baltic and North seas into land, and unite Great Britain with the continent. While such a change would add much new land to Europe, it would affect adversely the climate and commerce of large areas of existing land (How ?). It would also modify greatly conditions in Great Britain. Isolation from the continent has freed the United Kingdom from the need of maintaining a large standing army, and so added many thousands of men to the productive population. On the other hand, it compelled the development of extensive sea interests, and the maintenance of a large navy to protect them. Most oceanic islands not on the continental shelves are volcanic cones, or coral islands associated with them. Their combined area is only about three-fourths that of the state of Illinois.

Grouping of the continents. The northern hemisphere contains more than twice as much land as the southern. If the earth be divided into two hemispheres, one with its center in England and the other in New Zealand (Fig. 25), the first would contain about six-sevenths of all the land, and might be called the *land hemisphere*,

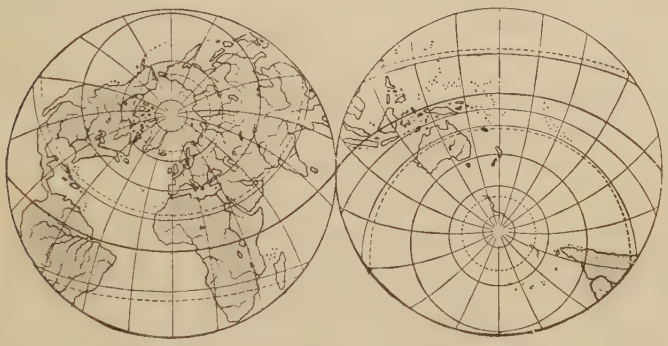

Fig. 25. Land and water hemispheres.

while the other would contain only about one-seventh of the land, and might be called the *water hemisphere*. Even in the land hemisphere, however, the water would cover rather more than half the surface, while in the water hemisphere it would cover about fourteen-fifteenths of it. Since the northern hemisphere contains two-thirds of the land, and a still larger proportion of the productive land, it has always supported a vast majority of the human race.

The irregular grouping of the continents follows no known law.

Origin of relief features of the first order. The ocean basins and the continental platforms seem to have been very much as they now are for millions of years. It is probable that the ocean basins have sunk below the continents, rather than that the continents have been raised above the ocean basins. The reason for this belief is that the earth is cooling, and therefore shrinking, and shrinking means that the outside is on the average getting nearer to the center. This must result in a sinking of the surface, in some places at least.

Past changes. If the sea bottom were to sink now, the ocean basins would hold more, and some of the sea-water would be drawn off the continental shelves. If the bottoms of the ocean basins were to sink 600 feet, or a little more, *all* the water would be drawn off the

continental shelves, and they would then become land. If the continents were to sink, the sea would spread over their low borders, reducing the area of land. The history of the earth teaches that the areas of ocean and land have changed somewhat from time to time. The lower parts of the continents have been drowned repeatedly, but it is not known that any part of the *deep* sea bottom was ever land, or that any part of the land was ever beneath a *deep* sea.

Relief Features of the Second Order

The more strongly marked features of the continents and of the ocean basins are relief features of the *second order*. The continental areas are made up of *plains*, *plateaus*, and *mountains*. Some of their relations are shown in Fig. 24.

Plains. *Plains are the lowlands of the earth,* yet they cannot be defined in terms of height above the sea. They may be but a few feet above it, or they may be hundreds or even thousands of feet above; but if so high as a thousand feet, they are generally far from the sea, and distinctly lower than some of the other lands about them. Plains differ widely among themselves, not only in height, but in position, size, shape of surface, fertility, origin, and in various other ways. Different names are given to various sorts of plains, the names being intended to call attention to some one feature. Important classes of large plains are *coastal plains*, which border the sea, and *interior plains*, which are far from the sea, or separated from it by high lands. The Atlantic and Gulf coastal plains illustrate the first class, while a large part of the area between the Appalachian Mountains and the Rocky Mountains is a great interior plain (Fig. 148).

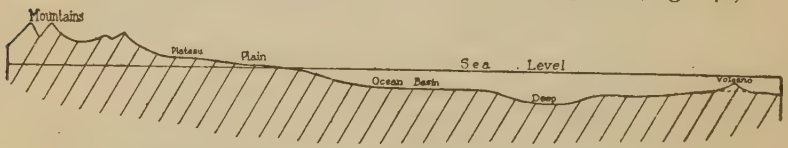

Fig. 26. Diagram to illustrate the relations of mountain, plateau, plain, ocean basin, and ocean deep.

Plateaus. *Plateaus are highlands with considerable summit areas;* but no great elevation is necessary to make a flattish area of land a plateau. In general, a plateau is so situated as to appear high from at least one side. Thus if a coastal plain rises gradually from the sea

to a height of 200 feet, and then rises by a steeper slope to another broad tract of land which stands 200 feet higher (Fig. 26), the upper tract would be called a plateau, not so much because of its altitude above sea-level, as because of its distinct rise above the plain along one side of it. The Piedmont Plateau, which lies between the Appalachian Mountains and the Atlantic Coastal Plain is not very high, but it is enough higher than the Coastal Plain to be distinctly set off from it. A large part of this plateau is, however, not so high as much of the great interior plain of the continent.

Some plateaus lie between mountains on the one hand and plains on the other, as in the case of the Piedmont Plateau. Others lie between mountains, as the plateaus of central Asia (Fig. 27), Mexico,

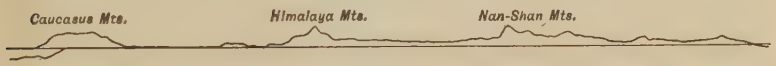

Fig. 27. Section across Asia, showing plateau between the Himalayas and the Nan-Shan Mountains.

Fig. 28. Section across North America, showing plateaus between the mountains in the western part.

and western United States (Fig. 28). Such plateaus do not appear higher than their surroundings. Other plateaus rise directly from the sea, as Greenland and parts of Africa. The total area of plateaus is great, though less than that of plains.

Mountains. *Mountains are conspicuously high lands which have slight summit areas* (Fig. 29). The tops of the loftiest mountains are between five and six miles above the sea, but most mountains have not half this height. The highest mountains tower above any plateaus, but many mountains are lower than the highest plateaus. Few mountains reach the height of the Plateau of Tibet, 15,000 to 16,000 feet.

Mountains are unlike plateaus of similar elevation in having little area at the top. In the case of mountain *peaks*, this is shown by the name. A mountain *ridge* or *range* may be long, but in most cases its crest is narrow (Fig. 243). Numerous peaks or ranges may be associated, making a mountain *group* or mountain *chain*; but even

in great mountain groups there is no great unbroken expanse of high land.

Where mountains rise abruptly to great heights above their surroundings, they are the most impressive and awe-inspiring features of the earth. In not a few cases they rise from low, warm plains

Fig. 29. Mountains rising conspicuously above a plain. Southern California.

to such heights that their summits always are covered with snow (Fig. 30). Nowhere else are such extremes of climate found so close together.

Mountains are the third of the three topographic types of the second order, as they appear on the lands of the earth. In this grouping of mountains, only great groups or systems of mountains, such as the Appalachians, the Rockies, the Alps, the Himalayas, and the Andes, are considered. Since the term "mountain" is applied to any point or ridge of such steep slopes and so much above its surroundings as to be conspicuous, it follows that many elevations called mountains (Fig. 30) do not belong to the great physiographic type which is to be brought into contrast with plains and plateaus.

It is noteworthy that mountain ranges are situated in general near the edges, rather than in the interiors, of the land masses, and that most of the loftier mountain chains are not far from the shores of the greatest ocean. The continental slopes to the Pacific Ocean are therefore shorter and steeper than those to the Atlantic and Arctic oceans. It is estimated that slightly more than half the land of the world drains to the latter oceans (Atlantic, 34.3%; Arctic,

Fig. 30. Sketch showing range from tropical vegetation on lowlands, to snow-fields on mountain, a common condition in the tropics. Orizaba, Mexico. (From photograph by Land.)

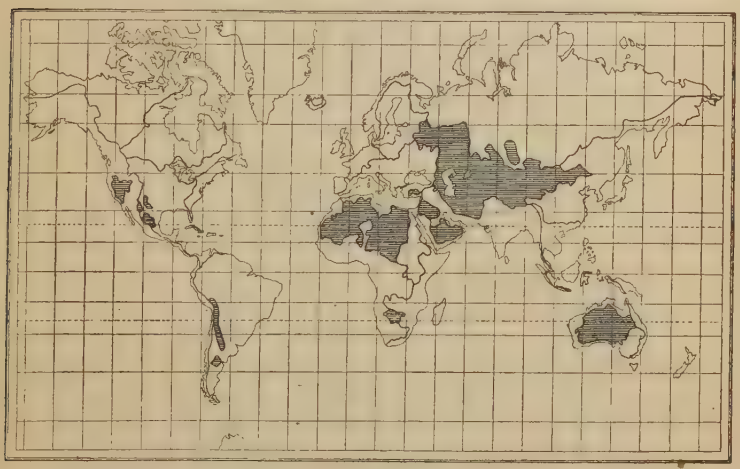

Fig. 31. Map showing drainage areas tributary to the different oceans, and areas of interior drainage (shaded).

16.5%). One-seventh (14.4%) drains to the Pacific, and about one-eighth (12.8%) to the Indian Ocean. The drainage of the rest of the land (22%) fails to reach the sea, and is lost in dry interior basins. Some of these basins, as in central Asia and western United States, are nearly surrounded by high mountains. Fig. 31 shows the areas tributary to the several oceans.

Subordinate Topographic Features

The surfaces of most plains and plateaus are uneven, while the very name of mountain suggests ruggedness. Irregularities of surface consist of elevations, such as *ridges* and *hills*, above the general level, and of depressions, such as *valleys* and *basins* (depressions without outlets) below it. The elevations and the depressions are bordered by *slopes*, which, when steep, are called *cliffs*. Ridges, hills, valleys, basins, flats, and cliffs affect mountains, plateaus, and plains; but in most cases they are more pronounced in mountains and plateaus than on plains. These minor unevennesses of surface are *topographic features of the third order*. The key to their history is found in changes now taking place on the land (Chapter XV), or in those which have taken place in recent times.

Comparison of the Continents

The position, form, size, and general relief of the continents are of fundamental importance, since these things determine, in large measure, their fitness for human occupation. *Europe*, the smallest continent except Australia, lies almost entirely in the north temperate zone. It widens rapidly toward the south, so that its east and west extent along the line of the Mediterranean, Black, and Caspian seas is nearly three times that along the Arctic Ocean. No other continent has an outline so irregular. Great arms of the sea extend far inland, modifying climate and helping commerce by bringing most parts of the continent into close contact with the sea. More than half of Europe is less than 600 feet above sea-level, and only one-sixth is over 1,500 feet. Many rivers serve as natural highways into the interior. Some of those in the west are unfrozen throughout the year. Europe has no tropical section, and no dry desert.

Asia, the largest of the continents, is nearly 4½ times the size of Europe, and nearly 5½ times as large as the United States. It

extends somewhat farther north than Europe, and much nearer the equator. Less than one-fourth of Asia is below 600 feet above the sea, and about one-sixth is above 6,000 feet. The average elevation is nearly three times that of Europe. A central region of high plateaus and mountains receives little rain, and is of slight value to man. The longest drainage slopes are toward the Arctic. Because of these things, one-half of Asia is relatively inaccessible. Asia has only about one-third as long a coast-line as Europe *in proportion to its area*. Its great size and relatively compact form make it the continent of climatic extremes. From a physical standpoint Europe and Asia form one continent (called *Eurasia*), but for historical and other reasons they usually are separated.

Australia is only a little larger than the United States, and is divided approximately in halves by the Tropic of Capricorn. The coast, though less regular than that of Africa and South America, has few harbors compared to Europe and North America. Because of its position, size, compactness, and topography, much of interior Australia is arid (p. 167). Australia is the most isolated of the continents.

About two-thirds of *Africa* are within the tropics. Broadly speaking, the continent consists of a great plateau, bordered in places by a very narrow coastal plain. At the south, the plateau is 3,000 to 5,000 feet above sea-level; at the north, 1,000 to 2,000 feet. Only one-eighth of the land (less than in any other continent) is below an elevation of 600 feet. The rivers descend in rapids or falls to the coastal lowlands. More than one-third of the continent is desert, while large areas in addition are semi-arid. Africa has the most regular coast of any continent. Europe, the most highly indented, has more than six times as much shore-line as Africa, in proportion to its area. Although one of the most ancient civilizations had its seat in Egypt, Africa has remained to our own day the "dark continent." The conditions indicated above have helped greatly to bring this about. The fact that much of the coast was devoid of harbors, and that navigation of even the larger rivers was interrupted near their mouths by falls and rapids, delayed exploration, conquest, and commerce. Both the vast deserts and the dense equatorial forests retarded native progress, and discouraged European settlement.

Like Africa, *South America* is largely within the tropics and is very compact, with few great indentations, peninsulas, or islands. On the other hand, the proportion of desert is much less, and of low-

lands much greater. Two-fifths of South America are below 600 feet, and two-thirds under 1,500 feet.

In *North America*, as in Europe, most of the land is in middle latitudes. Unlike Europe, North America presents its greatest width to the cold polar seas. North America ranks next to Europe and South America in the relative extent of its lowlands. Nearly one-third of the continent is below 600 feet, and nearly two-thirds below 1,500 feet. The vast interior plain stretching from the Arctic Ocean to the Gulf of Mexico has an unequaled system of navigable waterways. Except Europe, North America has the longest shore-line in proportion to its size. The greatest indentation, the Gulf of Mexico, affects the climate of eastern United States profoundly (p. 132). Except in the far north, most of the indentations have commercial importance.

Questions

1. South America and Africa have few islands about their borders. What does this *suggest* concerning the width of their continental shelves? Does it *prove* anything about the width?

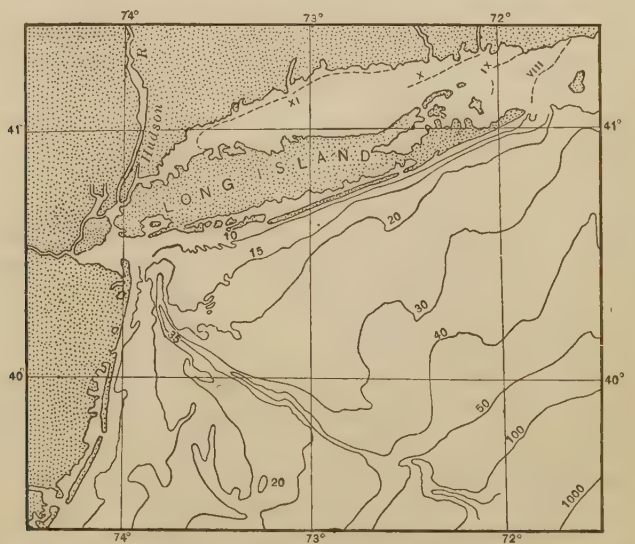

Fig. 32. Map showing valley-like depression extending across the continental shelf from the Hudson River.

2. Soundings along the eastern coast of the United States have shown that depressions like river valleys extend across the continental shelf from the mouths of various rivers (Fig. 32). What was the origin of those parts of the continental shelf in which these depressions occur?

3. From the comparison of the continents given on pages 40–42, which ones appear best fitted to contain the most advanced nations? Which ones seem least fitted to do so?

4. Most people live on plains. Would it therefore be better, from the human standpoint, if the earth were without mountains? Reasons?

CHAPTER IV

THE NATURE AND FUNCTIONS OF THE ATMOSPHERE

General Conceptions

Relation to rest of earth. The atmosphere is often called an *envelope of the earth.* It is, however, a part of the earth, held by gravity to the rest of the earth, with which it moves through space. Air is essential to the life of the earth, and to most of the processes in operation on the earth's surface. It helps to distribute moisture, it makes the extremes of heat and cold less than they would be if it did not exist, and it is a leading factor in the formation of soil. Furthermore, the atmosphere is not merely an envelope of the rest of the earth, for it goes down into the soil and rocks as far as there are holes and cracks, and its constituents are dissolved in the waters of sea and land.

Weight of air. When the atmosphere is still, we are hardly conscious of its existence, but many familiar phenomena show that air is very substantial. Thus wind, which is only air in motion, may be so strong that trees and buildings are blown down by it. A wind blowing 30 miles an hour exerts a force of nearly 60,000 pounds on the side of a house 60 feet long and 20 feet to the eaves. The weight of the air may be shown in another way. If the air is pumped out of a cylinder whose top is covered by a thin piece of rubber, the rubber cover is pressed down into the cylinder. The force which presses it down is the weight of the air above. This shows that air is something real, has weight, and exerts pressure. The amount of its pressure, that is, its weight, is nearly 15 (14.7) pounds on every square inch of surface at sea-level. In other words, the weight of the air is equal to that of a layer of water completely covering the earth to a depth of 33 feet. The pressure of the air on the body of a man amounts to several tons, but this is not felt because it is balanced by the outward pressure inside the body.

Density. The atmosphere is made up of gases. The particles of which the air is composed are nearer together at low altitudes than at high altitudes. At the bottom of the atmosphere the air is pressed

down by all the air above; at the height of 1,000 feet the air is pressed down by all above that level, and so on. Hence the lowest air is under most pressure and is densest. One-half the atmosphere (by weight) lies below a plane about 3.6 miles above sea-level, and three-fourths of it below a plane 6.8 miles above the same level. The highest mountain is almost six miles high, so that nearly three-fourths of the atmosphere lies below the level of its top.

It is largely because the air is less dense at high levels that mountain-climbing is difficult. The body is not used to the lessened pressure, and it causes discomfort. The chief difficulty, however, comes from the fact that, though the climber may take in the same number of cubic inches of air each time he inhales, each cubic inch contains less oxygen, the higher he goes.

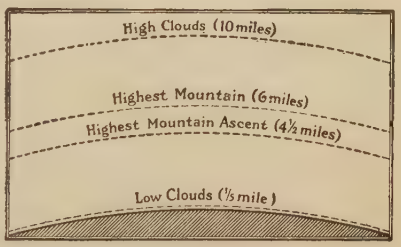

Fig. 33. Diagram to show relative altitudes in the atmosphere.

Height. The decreasing density of air at high altitudes suggests that, at some distance above the land, the top of the atmosphere may be reached. Though its actual height is not known, something is known about it (Fig. 33).

(1) The greatest altitude reached by any mountain-climber is about 24,000 feet. At this height there is air enough to make breathing possible to a climber. This shows that the air extends to a height of more than four and one-half miles.

(2) Men have gone up in balloons to heights of over six miles. In some cases, the men in the balloons became unconscious at an elevation of about 29,000 feet, and in other cases, where oxygen was carried for breathing, the chief discomfort was from cold. Balloons without men have risen eighteen miles. At this height the air is still dense enough so that the balloon did not sink. This shows that the air extends up more than eighteen miles.

(3) On almost any clear night "shooting stars" may be seen. Shooting stars, or *meteors*, are small, solid bodies which come into the earth's atmosphere from space outside. They are very cold when they enter the atmosphere, for the temperature of space is very low (believed to be about $-459°$ F.). In passing through the atmosphere, meteors are heated by friction with the air, and when they get red-hot,

they glow and may be seen. The height at which they begin to glow has been calculated in some cases, and found to be, at a maximum, nearly 200 miles above sea-level. This shows that the atmosphere is *much more than 200 miles high*, for the meteors *must have come through the rare, cold, upper air a long distance before becoming red-hot* by friction with it.

From these considerations it appears to be certain that the air extends more than 200 miles above the rest of the earth, but how much more is unknown. Except for a few miles near its bottom, it is, of course, very thin (rare).

Composition

Principal constituents. The composition of the atmosphere is nearly the same at all times and at all places where it has been analyzed. In its lower parts, at least, it is made up chiefly of two gases — (1) *nitrogen*, which makes up nearly 78 per cent of dry air, and (2) *oxygen*, which makes nearly 21 per cent. Some scientists think its composition at great heights may be very different from that below.

Beside these two gases, there are several lesser constituents, two of which, *carbon dioxide* and *water vapor*, are very important. The former makes up about $\frac{3}{10000}$ by weight of the whole atmosphere, and its amount is nearly constant from day to day, and from year to year. Water vapor is water in particles too small to be seen. The total amount in the atmosphere is not known to vary much, but the amount varies greatly from place to place, and it varies much from time to time in the same place. Even in the driest deserts the air is never without water vapor. Several other gases exist in the air, but among them *ozone* only is known to be of much importance.

The gases of the air are mixed with one another, and each of them retains its own qualities in the mixture. The oxygen behaves much as if no nitrogen were present, and the nitrogen as if there were no oxygen.

Impurities. The air always contains some gases which must be looked upon as impurities, though they are not necessarily harmful to life. Some such gases arise from the burning and decay of organic matter, others from chemical processes used in manufacturing, and still others from volcanic and other vents in the earth's crust. Although the total amount of gas which enters the air in these ways is small in comparison with the volume of the atmosphere, it would

doubtless be most impressive could it be stated in terms of weight or volume. For example, it is estimated that at least 1,000,000,000 cubic feet of natural gas escape unused into the air each day in the United States. Quantities of gas are poured into the air, too, from chimneys. In great manufacturing centers, gases from chimneys may be a source of discomfort to the people. The air always contains, as impurities, numerous solid particles, principally germs or other organic matter, and the commoner forms of dust. These vary in amount and character from place to place, and from time to time.

Relations of the Different Constituents to Life

Nitrogen. The various constituents of the atmosphere serve different purposes. Nitrogen is inactive. Though it enters the lungs with oxygen in breathing, it does not appear to be of direct use to animals. Indeed, its chief function in relation to life is often said to be "to dilute the oxygen." It is important to note, however, that *indirectly* nitrogen is of great importance to both plant and animal life. Man requires for his food considerable quantities of *proteids*, substances which contain nitrogen combined with other things. He obtains the proteids either from plants, or from animals which derived them from plants. Most plants use the small quantities of nitrogen compounds in the soil in forming proteids. Nearly all crops, if grown year after year in the same place, take out so much of the nitrogenous matter as to decrease the fertility of the soil. A few plants, such as clover, alfalfa, peas, and beans, add nitrogen to the soil. Certain bacteria associated with these plants take nitrogen from the air and combine it with other elements, and the plants then store the combined nitrogen in their roots, stalks, etc. It is therefore highly advantageous to grow nitrogen-fixing plants in rotation with other crops, and turn them under the soil. The nitrogen of the air is also drawn upon directly for the manufacture of fertilizers by electric processes. The pressure of the air, the force of the wind, and all other mechanical effects of the atmosphere are due largely to the nitrogen, for it makes more than three-fourths of the air by weight.

Oxygen. Oxygen from the air is consumed all the time by animals. Air-breathing animals take it from the air directly, and water-breathing animals take it from the water in which it is dissolved. The energy expended in human activities is derived from a union of the carbon of the blood with the oxygen taken into the lungs. The

product of the combination (*carbon dioxide*) is breathed back into the air. Oxygen is consumed by plants also, especially by green plants, and it is used wherever combustion (burning) or decay is going on, for combustion is primarily the union of oxygen with carbon, and decay is very slow combustion. The heat developed by combustion (as of coal) warms houses, and produces steam to run trains, drive machinery, and serve man in numerous other ways. Oxygen from the air combines with various constituents of rocks to form new compounds, and in so doing helps to form soil (p. 261).

In spite of the fact that oxygen is being consumed all the time, its amount does not appear to grow less, from year to year. We infer, therefore, that it is supplied to the air about as fast as it is used up. Plants break up the carbon dioxide of the air into carbon and oxygen, and set some of the oxygen free. This is the greatest source of supply. Small amounts of oxygen also reach the atmosphere from volcanic vents, and in other ways. It will be seen that plants, through their relation to oxygen and nitrogen, play an important part in supplying animals with both these elements.

Carbon dioxide. The carbon dioxide (CO_2) of the atmosphere, though a small constituent, is extremely important. It is being produced constantly by the burning of all kinds of fuel and by the decay of all organic matter. It is also added to the air by animal respiration. Every 1,000,000 human beings exhale about 2.5 tons per hour. It also issues from many volcanic vents in great quantities.

From these various sources, carbon dioxide is supplied to the atmosphere rapidly. About 75 per cent of common bituminous coal is carbon. The carbon of a ton of such coal, united with oxygen from the air (3 lbs of carbon unite with 8 lbs of oxygen), would make more than 2¾ tons of carbon dioxide, all of which goes into the atmosphere. A ton of hard coal, which contains more carbon, would produce still more carbon dioxide. The railroads of the United States alone burn about 100,000,000 tons of coal yearly. This means about 275,000,000 tons of carbon dioxide from that one source. Nearly a billion tons of coal are mined each year, and most of this is burned. When all sources of carbon dioxide are considered, it seems safe to say that carbon dioxide is being supplied to the atmosphere at the rate of about 75 tons per second.

Because of its close relations to combustion, respiration, and decay, the amount of carbon dioxide in the air of cities is greater than

in the open country. The amount in the air of London occasionally becomes five times the normal quantity, while in badly ventilated school-rooms, theaters, and workshops, it is sometimes ten times the normal amount. The conditions which lead to larger amounts of carbon dioxide in city air usually mean a corresponding increase in the amounts of various other harmful gases. Such conditions are injurious to health, and tend to make the residents of a large city less robust than the inhabitants of the country. The widespread movement to "purify city air," largely by the elimination of smoke, is an attempt to remedy these conditions.

In spite of constant additions, the amount of carbon dioxide in the air does not increase permanently enough to be noted. This gas, therefore, must be taken out of the atmosphere about as rapidly as it comes in. It is taken from the air chiefly (1) by green plants, of which it is the main food, and (2) by uniting with mineral matter in the solid part of the earth. It supports not only most plants, but indirectly most animals, for the latter feed on vegetation, or on other animals that live on plants. By uniting with mineral matter it helps to form soil.

It will be seen that some of the CO_2 is making a continuous round of change. It is taken out of the air by plants, and its constituents, notably carbon, become a part of the plant. In this process some of the oxygen is set free in the air. The carbon of the plant is then burned, either in a fire or by decay, and the carbon dioxide thus produced passes back into the air, to be used by plants again. Much carbon dioxide goes through this round each year, for much vegetation grown during one growing season is burned or partially decays before the next.

The supply and loss of carbon dioxide so nearly balance that no change in the amount of this gas in the air is noted from year to year; but it seems quite possible that, in the course of long periods of time, the supply may have exceeded the loss, or that the loss may have exceeded the supply.

Small as the amount of carbon dioxide is, it has still other important functions. The earth is constantly radiating heat into space, somewhat as a hot stove radiates heat into its surroundings, and carbon dioxide has the power of holding much of this heat. It therefore serves as a blanket to hold in the heat of the earth, and, thin as the blanket is, it is more effective, in this respect, than the denser blanket of oxygen and nitrogen. If it were thicker, it would be still warmer.

If the amount of this gas were doubled, it is thought that the temperature of high latitudes would be notably increased, possibly enough to melt the ice of Greenland.

A considerable decrease in the amount of carbon dioxide in the air may have been chiefly responsible for several widely separated periods of much lower temperature in the distant past, when great areas in various parts of the world were covered with snow and ice. Some of these areas are within the tropics, and now have very warm climates.

Water vapor. The water vapor in the atmosphere is a variable quantity. It is all the time entering the atmosphere by evaporation, and it is all the time being condensed and precipitated from the atmosphere as rain, snow, etc., to be again evaporated, condensed, and precipitated. The larger part of both water vapor and carbon dioxide is in the lower part of the atmosphere. Like much of the carbon dioxide, the water vapor is making continuous rounds. Its precipitation supplies the water for wells, the flow of springs, the maintenance of lakes, streams, and glaciers, and for the life of plants and animals. The bodies of animals, including human beings, are about four-fifths water. The tissues of annual plants are three-fourths water; of perennials, nearly half. To produce a bushel of corn, from 10 to 20 tons of water are required.

The amount of water vapor which the atmosphere is capable of containing at any time depends on temperature; but other things, such as the available supply, help to determine the amount which there is in the air in any one place. Like the carbon dioxide, the water vapor of the air helps to keep the earth warm.

Ozone. Ozone is the only other important constituent of the atmosphere. Its amount is greater over the ocean than over the land, greater in the country than in the city, greater in winter than in summer, and in summer, usually greater after thunder-storms. Ozone, which is an unstable form of oxygen, has powerful bleaching and disinfecting properties. Interesting claims are also made concerning its health-giving properties. Its real value in this respect is, however, not known, and in more than minute quantities it is injurious to man. It is probable that its chief value to health lies in the fact that its presence is a guaranty of air free from the injurious products of organic decay. Its value as a disinfectant has led to its manufacture for that purpose.

Dust. All the solid particles held in the air are dust. They are not ordinarily seen except on dry, windy days, but dust from the air

is constantly settling everywhere, indoors and out, whenever the air is dry. Dust may be seen readily indoors if a room is darkened and light allowed to enter through a narrow crack or small hole. Even air which appears clear may in this way be seen to contain countless particles of solid matter. The amount of dust is sometimes very great, as over cities, and in dry and windy regions. During the fogs of February, 1891, it was estimated that the amount of dust deposited on roofs in and near London was six tons per square mile. One effect of breathing dust-polluted air is a greater prevalence of diseases of the lungs, like tuberculosis.

Some years ago a method was devised for counting the dust particles in a given volume of air. The result showed that in the air of great cities there are hundreds of thousands of dust particles in each cubic centimeter (a cubic centimeter is less than $^1/_{16}$ of a cubic inch) of air; and that even in the pure air of the country, far from towns and factories, there are hundreds of motes per cubic centimeter. It has also been estimated that "every puff of smoke from a cigarette contains about 4,000 million separate granules of dust." The amount of dust in the air is greater over the land than over the sea, and in the lower atmosphere than in the upper. Like carbon dioxide and water vapor, most of the dust is found below an altitude of 10,000 feet. Its relative absence at high altitudes increases the intensity of the sunshine there by day, and helps to bring about low temperatures at night.

Dust consists of (1) *inorganic materials*, such as tiny particles of mineral matter blown up from dry roads and fields or shot out of volcanoes, and particles of carbon (soot, etc.) from chimneys; and (2) *organic particles*, such as bacteria and spores of plants. In many cities smoke from dwellings, factories, railroad engines, etc., constitutes one of the leading sources of atmospheric dust. Such smoke is largely unconsumed fuel. It is estimated that in the United States at least 20,000,000 tons of coal (carbon), representing a value of $40,000,000 or more, go up the chimneys each year in smoke. This enormous waste can be largely prevented, and when it is done the air of many great cities will be much purer than now. One of the most important results will be the increased comfort and improved health of the people living in such places. Bacteria pass with air into the lungs, and so reach the blood, where some of them multiply rapidly. Some of them cause disease, while others are harmless or beneficial. Many bacteria cannot endure much sunlight, and depend

on dust particles for their transportation; hence their number tends to be greater where there is little sunlight and an abundance of dust, as in great cities, especially in their crowded parts. Over the ocean, in the open country, and at high altitudes, on the other hand, bacteria are few. The number of bacteria found in a cubic meter of air at the Montsouris Observatory, near Paris, was 345, while in the same amount of air in the heart of the city the number was 4,790. These figures give some idea of the relative purity of country and of city air, and explain, in large part, the health value of seashore and mountain resorts. Dust-free air is practically free from disease bacteria, hence the importance of getting rid of the dust and smoke of cities, as far as possible. It is claimed by some physicians that the impure condition of the air in cities is responsible for much criminality through its injurious effects on the nervous system.

Dust particles in the atmosphere are important in several other ways. They scatter the light of the sun, so as to illuminate the whole atmosphere. Without dust in the air, all shady places would be in darkness. The sun would probably appear in dazzling brilliance, shining from a black sky, in which the stars would be visible even in the daytime. The blue color of the sky and the sunset and sunrise tints are influenced by the dust in the atmosphere. Dust particles also serve as centers about which water vapor condenses. In this way dust is an important factor in increasing the number and duration of fogs, and the amount of cloudiness over cities where many fires produce large quantities of smoke.

History and Future of the Atmosphere

History. It is probable that the atmosphere has undergone changes in mass and volume in the course of its history. It was formerly supposed that the atmosphere was gradually becoming less, and that it would, in time, disappear. But this belief does not appear to be well founded. The atmosphere is now gaining various gases from volcanic and other vents (p. 301), and probably has always done so. It is probably getting gases from space also, and though the contributions from this source are small now, they may not always have been so. The atmosphere is losing as well as gaining. Some gases, especially light ones like hydrogen, probably escape the attractive control of the earth and pass off into space. Other constituents of the air, especially oxygen and carbon dioxide, are with-

drawn from the air, and locked up for long periods, at least, in the rocks. The rates both of supply and loss vary. When loss exceeds supply, the mass of the atmosphere must decrease; when supply exceeds loss, the mass must increase. It is probable that the variations in composition have been more important than those of mass and volume, at least in the later part of the earth's history.

Future. The probable future of the atmosphere is a matter of absorbing interest, especially because it is connected intimately with the question of the duration of life upon the earth. As implied above, there is no reason to think that the atmosphere is likely to disappear, to become less, or less favorable for life. The other supposed source of danger to life in general was the failure of the sun's heat. Its great and constant loss of heat was long thought to mean that its supply would soon be gone, and if the earth were not warmed by the sun, the temperature would be so low that such life as now exists could not live. But recent discoveries have revealed sources of great energy, heretofore unknown, in the sun, so that its heat and light-giving power will doubtless continue much longer than was once supposed.

In the light of present knowledge, we may therefore expect the earth to afford conditions congenial to life through a length of time which passes our comprehension. This means that all the resources of the earth should be used wisely, for they are likely to be needed by endless future generations.

Questions

1. Enumerate the conditions (all of them) under which there would be most dust in the country air at a given point in northern United States.

2. What conditions would favor an increase in the amount of dust in the air of cities in summer? In winter?

3. Compare and contrast the purity of the air (1) over oceans and over lands; (2) in dry and moist regions; and (3) at high and low altitudes.

4. Would you expect the average amount of CO_2 to be greater in the air of cities or of the open country? Why? What processes, on the other hand, tend to equalize the amount over country and cities?

5. Give at least three reasons why the amount of CO_2 in the air (especially of great cities) tends to vary in amount between summer and winter.

6. How would the amount of nitrogen in the air probably be affected if it were chemically active? The amount in the earth's crust?

7. Why do people accustomed to low altitudes breathe very much faster in high altitudes?

8. Indicate various ways in which the extreme elasticity of the air favors human activities.

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CHAPTER V

CLIMATIC FACTORS: TEMPERATURE

General Considerations

We have seen that the composition of the atmosphere affects life in important ways. Various other things connected with the atmosphere, which may be called *climatic factors*, play important parts in one way or another. The chief climatic factors are (1) *temperature*, including the heating and cooling of the atmosphere; (2) *moisture*, including evaporation, clouds, and rainfall, and (3) *air movements*, or wind.

Importance of heat. Were it not for the effect of the atmosphere on temperature, the heat by day and the cold by night would be intolerable, and the earth would be a desolate, lifeless waste. Temperature, therefore, is hardly less important than oxygen, carbon dioxide, and water vapor—the life-supporting elements of the air.

The temperature which concerns land life chiefly is the temperature of the air in which it lives. Heat is received by the air from several sources, but the heat from the sun is so much greater than that from all other sources that it alone need be considered. That the atmosphere depends chiefly on the sun for its heat is shown by the variations in temperature from day to night, from cloudy days to sunny ones, and from season to season. Variations of temperature from time to time and from place to place are so important to all forms of life, including man, that it is necessary to have some easy way of measuring and recording them.

Measurement of heat. Temperature is measured by the *thermometer*, which consists of a glass tube of uniform diameter, except for a bulb at the lower end. The bulb and the lower part of the tube are filled with some liquid, generally mercury, and this is heated until it boils. The boiling mercury fills the tube and expels all air, and while it is boiling the tube is sealed, the heat being withdrawn at the same moment. On cooling, the mercury contracts and fills the lower part of the tube only. Whenever the temperature rises, the mercury

expands and rises in the tube, and when the temperature falls, the mercury contracts and sinks. The amount of rise or fall of the mercury shows the amount of change of temperature.

A scale is marked on the tube so that the temperature may be read from it. Two scales are in common use — the *Fahrenheit* (F.) and the *Centigrade* (C.). On the Fahrenheit scale the temperature of boiling water (at sea-level under normal pressure) is marked 212°; on the Centigrade scale, 100° (Fig. 34). The temperature of melting ice (*freezing point*) is marked 32° on the former scale, and 0° (*zero*) on the latter. Between the freezing and the boiling point on the Fahrenheit scale, there are 180 degrees, and on the Centigrade scale 100 degrees. It follows that 1° C. is equal to $1\frac{4}{5}$° F. Zero on the Fahrenheit scale is 32° below the freezing point, and 20° below zero Fahrenheit (written —20° F.) means 52° (32° + 20°) below the freezing point. The Centigrade scale is simpler and better than the Fahrenheit, and for that reason is used generally in scientific work, and in most European countries. The Fahrenheit scale is used chiefly in English-speaking countries, where the metric system of measurements has not been adopted as the standard.

Fig. 34. Diagram to represent Fahrenheit and Centigrade scales.

Records of temperatures, obtained by the use of the thermometer, are used in various ways. For the most part, however, they are used (1) *singly*, to indicate the temperature of a place at a definite time, as at 8 a. m., December 25; or (2) *in groups*, several observations being made at different times, and their average taken to represent the average temperature of a longer period. Thus from a sufficient number of temperature records, spread properly over a year, an average temperature for that year may be obtained. Similarly, averages for shorter periods, as seasons, months, and days, are possible. Such averages are usually called average *annual*, *seasonal*, *monthly* and *daily* temperatures. The average temperature of one year for a given place is, as a rule, somewhat different from that of the preceding or following year. So also the average for a given month in one year may depart much from the average of the corresponding month in other years. Thus at St. Paul, Minn., the average January

temperature in 1888 was —1° F., while in 1889 it was 21° F. Hence it is customary to take the averages of a great many years to get the *mean annual* temperature, or the averages for many Januarys to get the *mean monthly* temperature for that month. The highest and lowest temperatures during any period are called *maximum* and *minimum* temperatures; the average of the highest gives *mean maxima*, and the average of the lowest gives *mean minima;* the difference between them is the mean *range of temperature*. Thus there are many ways of using temperature observations.

Intense cold, —40° to —50° F., prevails, even in mid-summer, at altitudes 10 miles or so above sea-level. This is known from records made by the use of so-called *sounding balloons*, which carry instruments that record the temperature of the air through which they rise. The warmer temperature which we enjoy at the bottom of the atmosphere is due chiefly to the greater absorption by the denser, lower air, of (1) sun-heat, and (2) heat radiated from land and water, after they have been warmed by the sun. The temperature of space outside the earth's atmosphere is supposed to be about —273° C. (—459° F.).

Sun heating: insolation. The northern and southern hemispheres receive the same amount of heat from the sun each year, but, because of the inclination of the earth's axis, they do not receive the same amounts at all seasons. In fact, they receive the same amounts per day only at the times of equinox. The amount of heat actually received by the surface of land and water is far less than the amount coming to the top of the atmosphere, for much is absorbed in passing through the air.

(1) Other things being equal, the earth should get most heat per day where the sun shines the greatest number of hours. During a part of the summer of the northern hemisphere, latitudes above 66½° have sunshine continuously (except for clouds) for more than 24 hours. So far as hours of sunshine are concerned, therefore, these latitudes should receive more heat than other parts of the earth in summer. If there were no atmosphere, the surface of the earth at the North Pole would receive, on the 21st of June, about one-third more heat during 24 hours than the surface of an equal area at the equator, and about one-tenth more than an equal area in latitude 40° N. But the amount of heat which reaches the *bottom of the air* at the pole on the 21st of June, is materially less than that received at the bottom of the atmosphere in the other latitudes mentioned.

(2) Other things being equal, the surface of the land or water gets most heat where the sun's rays are most nearly vertical, because (a) the rays are there most concentrated, and (b) they pass through a less thickness of the air. This is shown by Fig. 35. A given bundle of rays, 1, falling vertically on the surface, is distributed over a given space, while an equal bundle of rays, 2, falling obliquely on the surface, is spread over a greater area, and therefore heats each part less. The rays oblique to the surface, 2, have passed through a greater thickness of air, and more of their heat has been absorbed by it before they reach the solid or liquid (ocean) parts of the earth. These facts help to explain why the surface at the pole does not get warmer than an equal area at the equator, even with months of continuous sunshine at the former place, and but 12 hours at a time at the latter. The snow and ice of polar regions prevent them from getting warm, even during the months when much heat is received (p. 60).

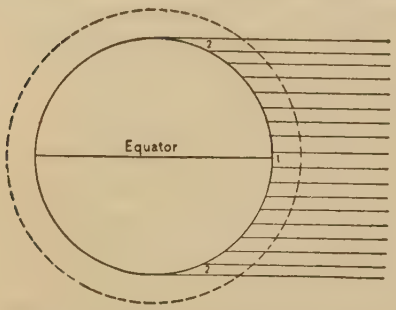

Fig. 35. Diagram to illustrate the unequal heating at the bottom of the atmosphere, due to the angle at which the rays of the sun reach the surface of the earth. The dotted line may be taken to represent the outer limit of the atmosphere.

The greater the angle of the sun's rays at any place (that is, the more nearly vertical they are), the greater the heat received by the surface at that place in any given time. The angle at which the sun's rays reach the earth varies from place to place, and from time to time at the same place, because of the inclination of the earth's axis. This is illustrated by Figs. 9 and 10, which have been explained. With no inclination of the earth's axis, the poles would receive very little heat from the sun at any time of year, and all places in corresponding latitudes in both hemispheres would always receive the same amounts of heat. In general, low latitudes receive the sun's rays less obliquely than high latitudes. In latitudes outside the tropics, slopes facing the equator receive the sun's rays less obliquely than horizontal surfaces. For this reason, the former should receive more heat than the latter.

Distribution of insolation. The distribution of insolation depends on the relative position of the sun with reference to the different parts of the earth at different times. From Fig. 11, which has been studied, we see that when the sun's rays come to the earth from the direction *W* (perpendicular 23½° south of the equator), they are more oblique than at any other time in the northern hemisphere, and less oblique than at any other time in the southern hemisphere. At the same time the days are longer in the southern hemisphere than in the northern. Hence there are two reasons why the southern hemisphere receives more heat than the northern at this season, namely (1) more nearly vertical rays, and (2) more hours of sunshine.

After the time (winter solstice, December 22d) when the sun's rays are vertical at 23½° S., they become perpendicular to the surface in latitudes farther and farther north, and on March 21st they are vertical at the equator. Days and nights are then equal everywhere, because all parallels are cut into two equal parts by the circle of illumination (p. 19), and the sun's rays are equally oblique in corresponding latitudes north and south of the equator. Any latitude in one hemisphere is then receiving the same amount of heat as the corresponding latitude in the other hemisphere. This condition would be permanent if the axis of the earth were not inclined.

After March 21st, the sun continues its apparent journey northward until June 21st, when its rays are vertical at the tropic of Cancer, 23½° N. The days of the northern hemisphere are then longest and the nights shortest, and the rays of the sun are then less oblique in this hemisphere than at any other time. At this time, therefore, the northern hemisphere is being heated more rapidly than at any other.

From June 21st to December 22d, the sun appears to move so that its rays become vertical farther and farther south, and the preceding changes are reversed.

The latitudes where the sun's rays fall vertically range from the tropic of Cancer to the tropic of Capricorn; and the sun's rays are, on the average, least oblique between these limits. This is why low latitudes are, on the whole, warmer than high latitudes.

The density of the atmosphere also affects the amount and intensity of the insolation received by the surface of the earth. Thus on mountains the less density of the air means more intense sunlight, and a greater amount of heat per unit of land surface, than is received

at sea-level (p. 62). One effect of this is seen in the rapid growth of plants on mountains in early summer.

Distribution of temperature. The temperature of one place is not necessarily higher than that of another because it receives more heat. No amount of heat, for example, would make Greenland warm until after the snow and ice were melted. The region about the North Pole does not get very warm, even when it receives much heat, because much of the heat received is expended in melting ice and in warming ice-cold water, which is warmed very slowly, and flows away as soon as the heating is well begun. Mountain tops are also generally cold in spite of the great intensity of insolation there.

After the heat from the sun has been received by the earth, it is redistributed to some extent, with the general result that the parts which get more by insolation share their heat with the parts which get less. The distribution of actual temperature, therefore, differs much from the simple distribution which insolation would give.

There are three ways in which the air receives, loses, and transfers heat. These are *radiation*, *conduction*, and *convection*.

(1) *Radiation. The sun always radiates heat*, and the surface which its rays strike is warmed by absorption of the radiated heat. A body need not be glowing hot, like the sun, or like fire, to radiate heat. The radiators in our houses radiate heat when they contain hot water or steam. The body which radiates heat is itself cooled. Thus a hot piece of iron soon cools in the air, because it radiates its

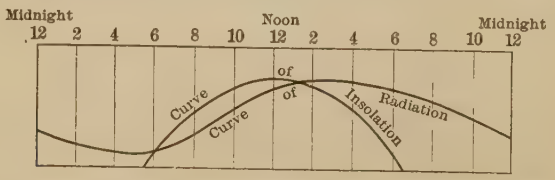

Fig. 36. Diagram showing curves of insolation and radiation. The maximum temperature of the day occurs near the higher crossing, the minimum temperature of the day near the lower crossing.

heat. The land warmed by the absorption of heat radiated from the sun during the day is cooled by the radiation of its absorbed heat during the night. The absorption of heat by day and its loss by radiation at night (Fig. 36) give variations of temperature between day and night. If the day is long and the night short, absorption of heat from the sun by day exceeds radiation by night, and the land tends to

become warmer, as in spring and early summer. If the day is short and the night long, radiation of heat will be greater than absorption, and the land will become colder, as in autumn and early winter. When land radiates more heat by night than it receives by day, the excess radiated is that which was stored up in the soil, rocks, and waters, in the warm season. The temperature of the land, therefore, is largely a matter of the balance between gain of heat by insolation during the day, and loss of heat by radiation at night.

(2) *Conduction.* If one end of an iron poker is put in the fire, the other end becomes hot. The heat seems to pass from one end to the other. This method of passing heat along is *conduction.* Any cold body in contact with a hot body is warmed by conduction. The hand is warmed by conduction when placed on metal or wood which feels warm; it is cooled by conduction if the metal or wood feels cool. The bottom of the air is warmed by contact with the land (that is, by conduction) wherever the temperature of the land is higher than that of the air. Conduction from the land to the bottom air is an important factor in determining the temperature of the air just above the ground.

(3) *Convection.* When a kettle of water is placed on a hot stove, the water in the bottom is heated by conduction, that is, by contact with the hot kettle. The heating of the water causes it to expand, and when the water in the bottom of the kettle expands it becomes lighter than the water above. The heavier water above then sinks and pushes the lighter water below up to the top. This sort of movement is *convection.* Another illustration of convection is afforded by stoves, fireplaces, and furnaces. A thin sheet of light paper may be held up for a moment by the rising air over a hot stove, or even carried up if the convection current is strong enough. Again, as the air in a chimney is heated, it expands and becomes less dense than the air about it. The cooler, denser air about the base of the chimney or stove crowds in below the expanded air in the chimney, and pushes it up out of the chimney. Since the air entering the chimney from below is being heated and expanded all the time, the up-draught continues as long as there is fire. Every draught from a chimney is an example of convection.

When the surface of the land is heated by the absorption of heat from the sun, it warms the air above both by conduction and by radiation. The lands of low latitudes are heated more than others. The heated air over the heated land expands and rises.

If the air in a given region were expanded as shown in Fig. 37, the air at the top of the expanded column would flow away, much as water would under similar conditions. *After this takes place*, the amount of air at the base of the column *h* will be less than the amount at the same level outside the heated area, and air from outside the heated column will flow in. This inflow will push up the column of expanded air, and further overflow above will cause further inflow below. If the heating continues, a permanent convection current is established in the heated area (Fig. 38). Such convectional movements in the atmosphere are important factors not only in distributing temperature, but also in causing winds, clouds, and storms, as we shall see. The summer whirlwind is an example of one kind of convectional movement due to heating of the land and the air above it.

Fig. 37. The first rise of air, as a result of heating, is due to the expansion of the part heated.

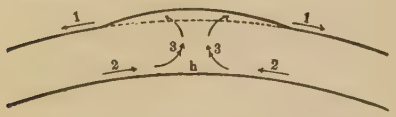

Fig. 38. The permanent heating of the air over a region gives rise to permanent convection currents.

The atmosphere is heated (1) by the absorption of the sun's rays as they come through it, (2) by the absorption of heat radiated from land and water, and (3) by conduction from warm land or water to the lower air. The amount of heat absorbed by air from the direct rays of the sun depends on the distance the rays travel in it, that is, on the obliquity of the sun's rays (Fig. 35). When the sun is vertical at the equator, the sun's rays pass through about twice as much atmosphere in latitude 60°, nearly three times as much in latitude 70°, and about ten times as much in latitude 85°, as they do in latitude 0°. The amount of absorption of sun-heat by the air, therefore, varies with latitude. About half of it is absorbed by the air at the equator, and about four-fifths at the poles, as compared with the total amount which would reach the earth in those latitudes if there were no atmosphere. In general, the amount of heat absorbed by the atmosphere may be taken as exceeding 50 per cent of the total amount coming to the earth from the sun.

The heat radiated into the air from below is absorbed by the air more readily than that coming from the sun directly. The lower

air is therefore heated by radiation from below more than by direct insolation.

After heat is received from the sun, therefore, it is redistributed, and the redistribution affects the temperature of the air. The redistribution is accomplished not only by radiation, conduction, and convection, but also by movements of air (winds) and movements of water (especially ocean currents). Without these movements of air and water, the average temperature of the equator would be much (perhaps 50° F.) higher than now, and that of the poles much (100° F. or more, estimated) lower than now. These changes would be destructive to many existing forms of life.

Temperature of land and water. Land is heated by insolation four or five times as fast as water, for several reasons:

(1) A given amount of heat raises the temperature of soil and rock more than that of water.

(2) Water is a good *reflector*, while land is not; the latter, therefore, absorbs a larger proportion of the heat of the sun's rays. The amount of heat reflected from a water surface increases with increasing obliqueness of the sun's rays. The major part of insolation on water bodies in high latitudes is lost by reflection. At the equator, for example, 40 per cent of the insolation goes into heating the water; in latitude 60°, less than 5 per cent is so used. Places so situated as to receive this reflected heat (as south-facing slopes on the north side of a water body in middle latitudes of the northern hemisphere) have their temperature materially increased. A familiar result of the reflection of heat from water appears in the intensity of sun-burn received on water. Snow-covered land and bare white sand reflect heat much as water does.

(3) Land absorbs heat more readily than water does.

(4) Convection movements are established in water as soon as its surface is heated. This prevents excessive heating at any one point. The land, on the other hand, being solid, is without movements of convection.

(5) There is more evaporation from a water surface than from a land surface, other conditions being the same, and evaporation cools the surface from which it takes place. A wet soil, receiving the same amount of the sun's rays, remains cooler than a dry soil. The hot sand of the desert and of the sea beach is an example of this effect on the warming of the land.

(6) Light and heat rays penetrate water, but not soil and rock

to any great extent. The heat of insolation is therefore distributed, at the outset, through a greater thickness of water than of soil. Being confined to the surface of the latter, its temperature is made higher.

Since the temperature of air tends to be the same as that of the surface on which it lies, the presence of land or water is an important factor in determining the temperature of the air above.

Seasons

In Middle Latitudes

We are now prepared to understand the seasons, and the reasons for their differences of temperature. In middle latitudes, the seasons are four — spring, summer, autumn, and winter. Each season has characteristics of its own, but each grades into the one which follows.

In the United States, March, April, and May are commonly called the spring months; June, July, and August the summer months; September, October, and November the autumn months; and December, January, and February the winter months. In the southern hemisphere, spring comes in September, October, and November; summer in December, January, and February, and so on. The vernal equinox of the northern hemisphere is the autumnal equinox of the southern, and the summer solstice of the northern is the winter solstice of the southern. The definition of the seasons given above is based on temperature, the warmest three months being summer, and the coldest three, winter.

The seasons are sometimes defined in a different way. Thus spring is sometimes regarded as the time between the vernal equinox and the summer solstice; summer the time from the summer solstice to the autumnal equinox, etc.

Summer and winter temperatures. The summer (June to August) heat of middle latitudes in the northern hemisphere is due (1) to the high altitude of the sun above the horizon, giving less oblique rays with a shorter path through the atmosphere, and (2) to the long days and short nights. During the long day, more heat is received than is lost during the short night. The reverse of these conditions accounts for the low temperatures of winter, though the earth is then actually 3,000,000 miles nearer the sun than in summer. A consideration of the position of the sun with reference to places in the southern hemisphere (Figs. 4 and 10) will make it clear why

summer there occurs at the time of the northern winter. One result of this difference of seasons in opposite hemispheres at the same time is that crops in the middle latitudes of the southern hemisphere are harvested in our late winter and early spring, when the northern supplies of certain things are running low. Hence there is important trade between the two hemispheres, places in each hemisphere being benefited because their crops ripen in the off season of the other.

The seasons in middle latitudes of the southern hemisphere are milder than those of similar latitudes in the northern hemisphere. Thus snow is very rare at Buenos Aires, Lat. 34° 36′ S., while at Wilmington, N. C., Lat. 34° 15′ N., an average of 1 inch falls every winter. The difference is due mainly to the greater proportion of water in the southern hemisphere. The extent of this effect is suggested by a comparison of temperatures, as follows:

	Midwinter Month	Midsummer Month
Buenos Aires	(July) 50° F.	(Jan.) 75° F.
Wilmington	(Jan.) 45° F.	(July) 80° F.

Warmest and coldest months. Since the northern hemisphere receives its largest amount of heat at the time of the summer solstice, and its smallest amount at the time of the winter solstice, it would seem at first that these dates, respectively, should be the times of highest and lowest temperatures; but this is not the case. Again, since corresponding latitudes in the two hemispheres are being heated equally at the time of the equinoxes, it would seem, at first, that these latitudes in the two hemispheres should have the same temperature at these times; but this, again, is not the case. In our own latitudes, for example, March 21st (vernal equinox) is much colder than September 22d (autumnal equinox).

The explanation of these conditions is found in the fact that the temperature of any given place at any given time is not dependent entirely on the amount of heat received from the sun at that time. In our latitudes, the surface becomes warmed during the summer, when the heat received during the long days is greater than that lost during the short nights. At the end of summer, therefore, the soil, rocks, lakes, and rivers have all been warmed. Heat has been stored up in them. At this time of year, therefore, the northern hemisphere has a temperature higher than that which it would have if it depended entirely on the heat received from the sun each day. On the other hand, the temperature at the time of early spring is lower than that which the daily heating would seem to produce, because

the cold of the winter just past has not been altogether overcome. Some of the snow and some of the ice of lakes, ponds, streams, and soils, in middle and high latitudes, is still unmelted. The snow and ice keep the lower part of the air cool.

For similar reasons, the summer solstice is not the hottest time of the year in the northern hemisphere, for the summer's heat has not yet altogether overcome the effect of the preceding winter. The time of greatest heat lags behind the time of greatest heating. In middle latitudes the lag is about a month; but it is more over oceans than over lands, because land is heated and cooled more readily than water. For this reason places near bodies of water usually have later and colder springs than places not so situated. Under such conditions, April may be as cold as November. For a similar reason, the time of greatest cold does not come till after the time of least heating.

In Tropical Latitudes

The seasons in low latitudes are unlike our own. At the equator, the sun's rays are vertical twice each year — at the times of the equinoxes. Twice a year, too, the sun's rays are vertical $23\frac{1}{2}°$ from the equator, once to the north and once to the south. The equator, therefore, has two seasons, occurring at the time of our spring and autumn, which are somewhat warmer than two other seasons occurring at the time of our summer and winter. The variations in temperature are much less than in our own latitude, for the length of day and night never varies at the equator, and varies relatively little in any part of the tropics. The angle of the sun's rays, too, varies less than with us. At the equator, therefore, there is a fourfold division of the year, but their differences of temperature are slight. In some places the warmest month is no more than $2° — 3°$ F. warmer than the coolest. Hence any seasonal division on the basis of temperature is unimportant. In the equatorial region, differences of temperature between day and night are greater, as a rule, than differences between the warmest and the coolest month. Differences in moisture perhaps offer a better basis than differences in temperature for a division of the year into seasons. Where wet seasons alternate with dry ones, the effect on life from season to season is great.

In High Latitudes

In high latitudes, the seasons are still different. About latitude 60°, for example, the differences in the seasons are similar to those

of the central part of the United States, except that they are greater, because of the greater variation in the length of day and night. In latitude 63°, the longest day of summer and the longest night of winter are about 20 hours each, as compared with a little over 15 hours in latitude 40°. The long nights of winter in latitude 63° mean much lower temperatures than in latitude 40° at that season. On the other hand, the long hours of sunshine in summer make it possible, in favored localities, to grow crops as far north as latitude 60°, even where it is only four months from snow to snow.

In latitude 75° N., which may be taken as typical of polar regions, there are four natural divisions of the year, one (summer) when daylight is continuous, one (winter) when darkness is continuous, one (spring) when there is alternating day and night, with the days lengthening, and one (autumn) when there is alternating day and night, with the nights lengthening. The lengths of the seasons defined in this way are not the same.

There is a common notion that in polar regions there is a day of six months and a night of six months each year, but this is not correct. There is a six-month day and a six-month night *at the poles only*. In latitude 78°, about half way between the pole and the polar circle, there is continuous daylight and continuous darkness for periods of about four months each. In latitude 70° the periods of continuous darkness and of continuous light are two months each, and so on down to 24 hours at the polar circle.

Though the name summer may be applied to portions of the year in high latitudes, it must be remembered that the factors controlling the distribution of heat and temperature do not allow places north of latitude 65° to become warm enough for the growth of cereal crops. Vegetation is confined to grasses, stunted shrubs, lichens, and moss. The conditions of life here are very different from those of middle latitudes. Hence the names of the seasons, as we use them, do not mean the same thing for any other than middle latitudes.

Relation of Temperature and Altitude

High altitudes are colder than low levels in the same region, (1) because the air is thinner, and (2) because it contains less water vapor, carbon dioxide, and dust. For these reasons it absorbs less heat from the direct rays of the sun, and less of that radiated from below. The result is that the temperature of the air at high altitudes

is low, though the heat of the direct rays of the sun may be uncomfortably great. Thus the air temperature on top of a mountain 12,000 feet high may be 30° or more lower than the air temperature at the base, in spite of the fact that insolation is 10 to 20 per cent greater in the former position.

The average decrease of temperature is about 1° F. for each 330 feet of rise, or 16° for each mile, for the altitudes where observations have been taken. One mile of ascent, therefore, means about the same decrease of temperature as a journey of 1,000 miles (about 15° of latitude) toward the poles. Hence tropical highlands, like those of Mexico or Bolivia, in latitudes 18° to 19°, N. and S. respectively, are really cooler than some places at sea-level in middle latitudes. For this reason, some countries in the tropics can produce not only tropical crops, but also those characteristic of other regions, and by living at the higher elevations, the people may escape the uncomfortable heat of tropical lowlands. In middle latitudes also vegetation varies with the altitude. Thus, in the low mountains of Pennsylvania, the ridges bear coniferous trees (pines, etc.) sugar maples, and similar types, while the valleys between have the honey locust, gum, and walnut, which need a warmer climate. In the latitude of Chicago, corn will not, as a rule, ripen at an altitude above 2,000 feet, though it flourishes on lower lands.

The low temperatures of certain mountains and high plateaus of the middle zones make them inhospitable, and help to condemn them to sparse populations. On the other hand, the cool climates of various upland areas in the tropics have permitted the establishment of permanent white settlements. During the hot summer months the capital of India was transferred each year from Calcutta (capital until 1911), near sea-level, to Simla in the Himalayas, at an elevation of 7,000 feet. Certain elevated places in the Philippines, like Baguio, the summer capital, will have increasing importance as health and pleasure resorts during the hot period.

A land surface at a high altitude may be heated more by the sun than one at a low altitude, and it then heats the air above it; but since the air over the high land is thin, it is heated less and does not hold the heat so well as denser air would. The result is that both land and air cool faster in high altitudes than in low ones, and this makes their average temperature less. The temperature of the air over land 10,000 feet high is warmer than the temperature of the air 10,000 feet above low land.

Isolated elevations like mountain-tops are colder than plateaus of the same elevation, because they are so well exposed to cooling. On clear days in summer, the sunny side of a mountain free from snow gets very warm (Fig. 39). If the rock is bare, it may become so hot that the hand cannot be held on it. If the air remained long in contact with such a rock surface, it would be warmed to the same temperature; but it is commonly moved on quickly by winds before it gets very warm, and its place is taken by colder air. Again, an isolated mountain-peak radiates heat in all directions except downward, while a flat surface radiates it upward only. These are some of the reasons why a volcanic mountain, like Cayambé, in Ecuador, directly on the equator, with an altitude of less than 20,000 feet, has its summit covered with perpetual snow, even though its altitude entitles it to the temperature of a place near sea-level in latitude 58°. Cereal crops are grown in Norway even north of latitude 58°. In mountains, too, there are likely to be many days when clouds shield the rocks from the sun. This tends to reduce the *average* temperature of the mountain, as compared with that of low land.

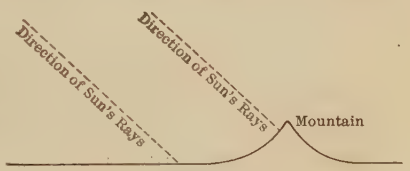

Fig. 39. Diagram to show that the sun's rays may fall less obliquely on a mountain slope than on a plain adjacent.

The difference in vegetation and in human conditions between the sunny and shady slopes of mountains is striking in many cases. Thus at various places in high latitudes there is a great contrast between the scattered, feeble vegetation of the lowlands, and the denser, more luxuriant growth on the sunny slopes of neighboring mountains. Fig. 39 suggests the reason for the difference. The sun's rays strike the surface of the plain much more obliquely than they do the side of the mountain, and their heating power is therefore less in the former place. At a place near Zermatt, in the Alps, barley and rye are grown on a sunny southern slope 6,900 feet above sea-level, while a few hundred yards away, northern slopes, even below the level of the grain fields, have arctic-alpine vegetation and snow-banks. In some of the valleys in the Alps, most of the people live on the sunny slopes, and those on the shady sides are in general less prosperous. These differences have developed in some places where the advantages, apart from insolation, are identical.

Where mountains are covered by snow throughout the year, *their surfaces are never warmed above a temperature of 32° F.*, the melting temperature of snow. All the heat received beyond that necessary to raise them to this temperature, is spent in melting and evaporating snow, not in raising the temperature of its surface. Yet in spite of the freezing temperature, travellers over the snow-fields may be sun-burned, as if exposed to mid-summer sun at lower altitudes. Part of this effect is due to the greater intensity of insolation at higher altitudes, and part of it to the fact that snow reflects heat much as water does (p. 63).

Representation of Temperature on Maps

The importance of temperature and its changes makes it desirable to have some means by which conditions in different places and at different times may be readily studied. Tables of figures may be used if only a few places are to be compared, but for large areas it is more convenient to have the temperatures shown on maps. Maps showing temperatures are *thermal maps*. On such maps temperatures and their distribution are commonly shown by lines, each of which connects points having the same temperature. Such lines are *isotherms*, and maps showing isotherms are *isothermal maps*. A line connecting places having the same average annual temperature is an *annual isotherm*. Lines connecting places of the same average seasonal or monthly temperature are *seasonal* or *monthly isotherms*. An isothermal map should always show whether the isotherms are annual, seasonal, or monthly.

Fig. 40 shows annual isotherms for each 20° F. The map does not give exact average temperatures for places between the lines, but temperatures for such places can be estimated from the maps. At the extreme north there is the isotherm of 0° F., which lies north of Europe and Asia, and barely touches North America. The average annual temperature of places on this line is 0° F. The isotherm of 10° F. lies south of the isotherm of 0° F. The average temperature of places between these two lines is more than 0°, and less than 10°. South of the isotherm of 10° follow, in order, the isotherms of 30°, 50°, 60°, and 70°. The lowest isotherm shown on the chart in the southern hemisphere is that of 30°, lying south of all lands except Antarctica. The latitude of this isotherm corresponds nearly to the latitude of the isotherm of 30° in the northern hemisphere. Next north (toward

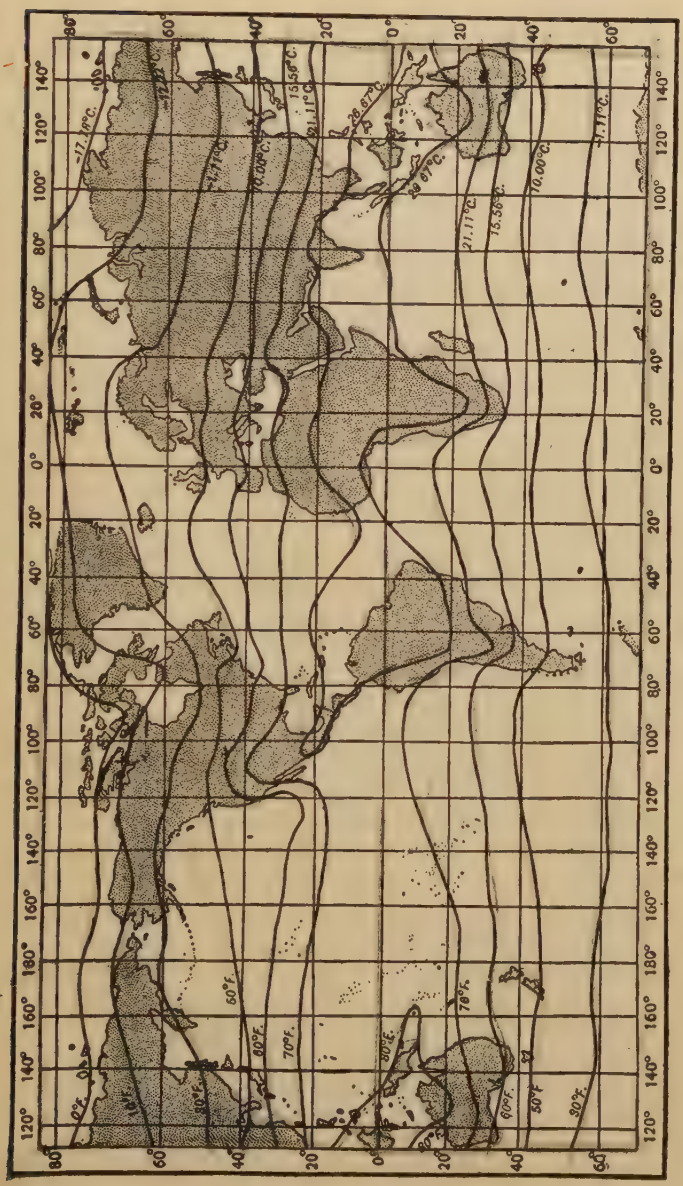

Fig. 40. Average annual temperatures for the world. (After Buchan.)

the equator) of the southern isotherm of 30° is the isotherm of 50°, followed by those of 60° and 70°. Thus the map shows the relation between latitude and annual temperatures, the highest temperatures being near the equator.

Annual isotherms do not show all we may want to know about the temperature conditions of a place. An annual isotherm of 50° F., for example, does not tell us whether the temperature is about 50° F. all the time, or whether it is 80° F. in summer and 20° in winter. Seasonal and monthly isotherms are of more significance in connection with crops, and give a better idea of the temperature conditions of a place. This may be illustrated by the fact that the annual isotherm of New York is about the same as that of southern England, while the summer isotherm of the former place is more than 10° warmer than that of the latter. Since summer temperatures are the most important for crops and for some human activities, the difference of more than 10° in that season is enough to make New York and southeastern England quite unlike in many respects. Again, San Francisco and St. Louis have the same mean annual temperature; but the January average is 10° from the July average at San Francisco, and 45° from it at St. Louis. *Range of temperature* is, therefore, important. The annual range of temperature for Quito, Ecuador, is 1° F.; that is, the warmest month is only about 1° warmer than the coolest. For San Diego, Cal., the range is 16° F.; for St. Paul, Minn., 60°; for Yakutsk, northeastern Siberia, 100°.

Fig. 41 shows the isotherms for January. On this chart corresponding isotherms are farther south than on the chart of annual isotherms. Thus the isotherm of 0° F. (—17.78° C.) in the northern hemisphere runs through central Asia, instead of lying north of it, and the isotherm of 60° is everywhere south of latitude 40°, instead of being partly north of it, as in Fig. 40. At this time of the year, the sun is shining vertically south of the equator. This seems to be a sufficient reason for the change.

Fig. 42 shows the isotherms for July. All isotherms are farther north than the corresponding ones on either of the other charts. Thus the isotherm of 50° in the northern hemisphere is about where the isotherm of 20° was in January (Fig. 41).

Comparing Figs. 41 and 42, it is seen that the difference of temperature between January and July is much greater in high latitudes than in low. Thus in the southern part of Hudson Bay there is 70° difference between January and July; at Lake Erie, about 45°; in

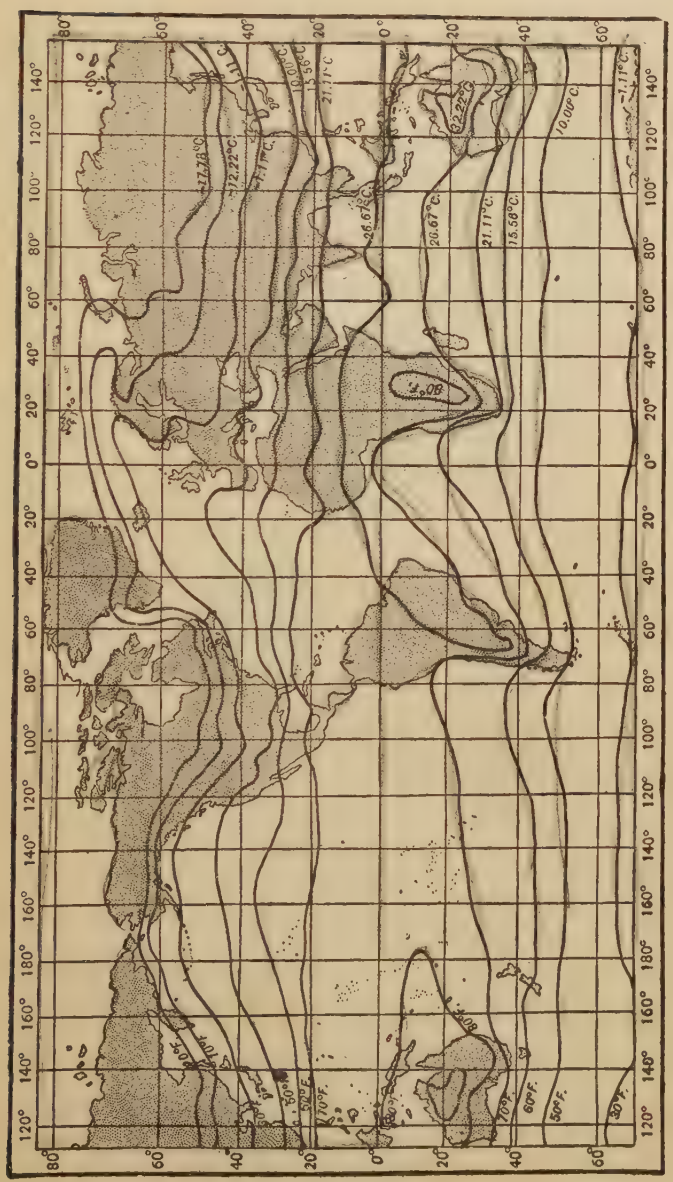

Fig. 41. Isothermal chart for January. (After Buchan.)

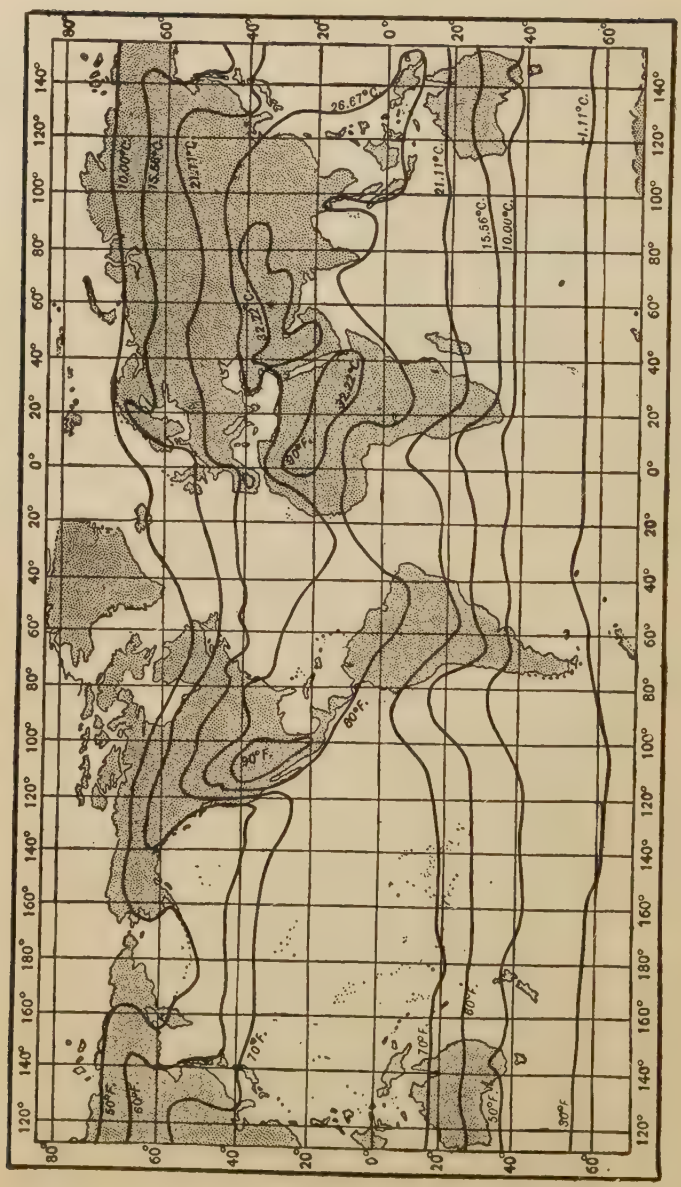

Fig. 42. Isothermal chart for July. (After Buchan.)

Florida, about 20°; and near the equator in South America, less than 10°. The same charts show that the difference is greater in the interiors of continents than on coasts or over the sea in the same latitude. Thus in the interior of North America, west of Hudson Bay, the difference is about 80°, while on the coast of Alaska it is only about 30°. These conditions bear out the conclusions already reached, (1) that the difference in the amounts of heat received at different seasons is greater in high latitudes than in low latitudes, and (2) that land heats and cools more readily than water.

The line of highest temperature about the earth is the *thermal equator*. The thermal equator does not follow a straight course around the earth, and its position shifts with the seasons. Most of the year, however, it is a little north of the geographic equator, due to the fact that there is more land north of the equator than south of it, and to the further fact that land is heated more than water (p.63).

The courses of isotherms. (1) The courses of the isotherms are, in a general way, east-west; that is, they are roughly parallel to the parallels of latitude. Some of them are very irregular, it is true, but the east-west direction is the most common one. This shows some relation between the courses of isotherms and *latitude;* but since the isotherms do not follow the parallels exactly, it is clear that latitude is not the only thing which determines their position.

(2) Figs. 41 and 42 show that the isotherms are least crooked where there is little land, and most crooked where there is much land. This suggests that the *land and water* have something to do with their positions. There are various irregularities in the isotherms on land that do not appear on the sea. Thus, on the January chart, there is an area in South Africa, and another in Australia, surrounded by the isotherm of 90°, and there are similar areas in North America, northern Africa, and southern Asia, in July. All of these areas are on land. These facts tend to confirm the conclusion that the sea and the land influence the position of the isotherms.

Following this idea still further, it is seen that some of the isotherms of January bend somewhat abruptly toward the equator in passing from water to land, and toward the pole in passing from land to water. Thus the isotherm of 30° in the northern hemisphere turns to the south where it reaches North America, and again on the coast of Europe. In the southern hemisphere, the isotherms of 80° and 70° make abrupt turns at the west coast of Africa, and the

isotherm of 70° near the west coast of South America. These bends at the coasts give further support to the conclusion that the distribution of land and water has something to do with the position of isotherms.

It has been noted already (p. 63) that the land is heated and cooled more readily than the sea, and is therefore colder in winter and warmer in summer. The January isotherm of 30° in the northern hemisphere bends toward the equator in crossing the northern continents, because the land is cooler than the water in the same latitude, at this time of year. In the southern hemisphere, on the other hand, where it is summer, the isotherms bend toward the pole on reaching the land, because the land is warmer than the sea in the same latitude.

The chart of the July isotherms leads to the same conclusion. On this chart the isotherms crossing the northern continents bend poleward on the land, while those crossing the southern continents bend equatorward. This is the season when the lands of the northern hemisphere are warmer than the seas of the same latitude, and when the lands of the southern hemisphere are cooler than the seas about them.

The irregularities of the isotherms of the northern hemisphere in July are much greater than those of the southern hemisphere in January (summer in the southern hemisphere). This is probably because there is much more land in the northern hemisphere than in the southern, and the larger land areas have a greater effect on the isotherms than the smaller ones.

(3) There are some features of the isothermal lines which are not explained by latitude, or by the distribution of continents and oceans. Thus the bends of the isotherms are not as pronounced on the east sides of the continents as on the west. This is shown by Figs. 41 and 42. Again, traced eastward, the January isotherm of 50° near the west coast of North America bends southward chiefly *on the land*, while on the eastern side of the continent it bends northward *on the sea*, not on the land. Such peculiarities may be explained by the *winds*. The prevailing winds in the middle latitudes of North America are from the west. These winds tend to carry the temperature of the sea (warmer in winter) over to the land on the western side of the continent (Fig. 41), and the temperature of the land (cooler in winter) over to the sea, on its eastern side. This explains the bends of the isotherm of 40°, for example, near the coasts in the

northern hemisphere in January. Coastal lands on the western sides of continents in middle latitudes tend to have temperatures like those of the neighboring ocean, and the extent to which this influence is felt over the land depends on the strength of the wind and on the topography.

(4) The great bend in the January isotherm of 30° in the North Atlantic is due to a northeastward movement of warm ocean water in the direction of the pronounced loop of the isotherm. *Ocean currents* are therefore a fourth cause of the irregularities of isotherms. The amount of heat carried northward by the ocean currents of the Atlantic and Pacific is very large. It has been estimated that the temperature of the British Isles and Norway is raised several degrees by the warm poleward movement of waters in the North Atlantic. The temperature of the land is raised by this water, because the air over the warm ocean water is warmed and then blown over the land.

The milder climate of northwestern Europe, as compared with northeastern North America, is not due wholly to the northward movement of warm water. Even without such movement, the climate of northwestern Europe would be somewhat warmer in winter than that of northeastern North America in the same latitudes. This is because the ocean, from which the winds of winter blow to northwestern Europe, still would be warmer than interior North America, whence the prevailing winds blow to the eastern coast of that continent.

There are some other less important causes of irregularities in the isotherms. Thus a basin region, shut in by mountains, gets hotter in summer than a region not so surrounded. Again, there is less evaporation from a dry surface than from a moist one, and since evaporation cools the surface, a dry surface will be warmer than a moist one, if other conditions are the same. The color of the soil, the presence or absence of vegetation, etc., also affect the absorption and radiation of heat. The high temperature (90° and above) in the southwestern part of the United States in July (Fig. 42) is accounted for partly by the fact that the region is somewhat shut in by mountains, and has a dry, sandy soil but scantily covered with vegetation.

Altitude affects temperature, as already explained, but isothermal charts show no relation between isothermal lines and surface relief. The reason is that isothermal lines are represented on maps

as if they were at sea-level. This is done by making allowance for altitude at the average rate of 1° F. for about 330 feet. Thus if the temperature of a place at an altitude of 3,300 feet is 60°, it is put down on the chart as 70° (60°+10°). Isothermal charts, therefore, are intended *to show the temperature as it would be if the land were at sea-level.*

Ranges of Temperature

Daily range. The temperature of a day when the sun shines is generally warmer than the temperature of the night. The difference is as much as 40° or 50° F. in many places, and as much as 70° in some. The daily range of temperature of air over the ocean is much less than over the land.

Questions: Were other things equal, would the daily range of temperature be greater (1) in high or low latitudes? (2) In high or low altitudes? (3) In moist or dry regions? (4) Where the surface is covered with vegetation or free from it? (5) Where the soil is light or dark colored? (6) Near the sea or far from it? Reasons in each case.

The daily range of temperature is a factor in the breaking up of rocks to form soil, but its greatest importance is in connection with the growth of most crops. Since many plants, including many food plants, are injured or killed by a freezing temperature (commonly called "frost"), they are restricted to regions where the temperature during the growing season does not fall to 32° F. at night. Hence to the farmer and fruit grower a freezing temperature is one of the most important things connected with atmospheric conditions. The danger of "frost" at night varies with local conditions, as (1) altitude, (2) exposure, (3) character of the soil, and (4) nearness to water bodies. Valley bottoms have frosts earlier in the autumn than neighboring hillsides, because the colder, heavier air moves down slopes and accumulates in low places. The great coffee plantations of São Paulo, Brazil, the olive and fig trees of Italy and Istria, the orange and peach orchards of California, and the vineyards in the Rhine Valley and in the south of France are found largely on hillsides. Locally, parts of a hillside are essentially free from frost. Such areas are called "frostless belts." Polk and Macon counties in North Carolina possess such belts, which are there used for growing special kinds of grapes. The Polk County belt lies at an altitude of about 1,500 feet, and extends for about 8 miles along the mountain side. In some of the fruit-raising valleys of the Northwest, it is

customary to speak of the "frost line," that is, the line on the slopes below which frost is likely to be destructive.

Northern slopes are more subject to frosts than are southern slopes, because the latter are warmed more by day and hence must cool more at night before a freezing temperature is reached. Sandy soils are more liable to frost than clay soils situated similarly, for the reason that clay soils are usually wetter. The air above them contains more moisture, and so cools less readily. The condensation of moisture sets free heat and so checks further cooling. Of two perishable crops on the same farm, one on clay soil, the other on sandy soil, the one may be untouched by "frost" on a night when the other is seriously injured. Moisture in the soil is always considered in making frost predictions. Localities near water bodies, and in their lee (i.e., on the side toward which the wind blows from the water), have their temperatures influenced by the temperature of the water. Hence rapid cooling at night in the autumn is somewhat less likely in such situations, and frosts are held off. The value of this relation is found in the location of important fruit districts on the lee (east) shore of Lake Michigan, and on the lee (southeast) shores of Lakes Erie and Ontario. A similar influence affects the important fruit and trucking industry of the peninsula between Delaware and Chesapeake bays.

Frost prediction. The probability of frost occurrence for any night can be predicted with much accuracy from the relation known to exist between (1) the temperature of the air, (2) its relative humidity, and (3) the amount of cooling necessary to reach the dew point.

Calculation of the dew point is made with an instrument known as the psychrometer, consisting of two thermometers mounted in such a way that they may be whirled rapidly in the air. One thermometer, of the ordinary type, is known as the dry bulb thermometer, the other, with the mercury bulb surrounded by a wet wick, is the wet bulb thermometer. As the instrument is whirled, evaporation from the wick causes the temperature of the wet bulb thermometer to fall below that of the dry bulb. The difference between the two readings and the temperature of the dry bulb (air temperature) is then referred to tables known as dew point tables, from which the temperature of the dew point for air of that temperature and humidity is determined. If this dew point temperature lies near to 32° F., and conditions are favorable for rapid radiation, frost occurrence is probable. Equipped with a psychrometer and dew point tables, anyone can make satisfactory observations on the probability of frost.

The economic importance of frost is so great that the federal government has given much attention to methods for protecting

perishable crops, and one of the most valuable services of the Weather Bureau is the sending out of frost warnings which give the farmers of the country anywhere from 6 to 24 hours to make preparation for protection. In this way, millions of dollars' worth of crops are saved every year. The cost of protection for several consecutive nights may not equal 1 per cent of the value of the crop saved.

Other effects of daily changes. The average daytime temperature during the growing season, and the number of days when the temperature is above a given point, are also important, since most plants require a temperature well above 32° F.

The daily range of temperature is also important to human beings, especially where the days are hot. Thus in desert regions the heat of midday may be much above 100° F.; but night temperatures in the same place may be as low as 45° or 50° F., making restful sleep possible. A station in the Sahara and one at Manila afford examples of difference of daily range.

	Daily mean.	Max. Day temp.	Min. Night temp.	Range.
Southern Tripoli	87°	106°	62°	44°
Manila	91°	96°	86°	10°

The heat in Tripoli is borne more easily than that of Manila, because of the relief at night in the former place. It is the daily range of temperature which accounts partly for the invigorating effects of a vacation in the mountains. Many famous Swiss health resorts, for example, depend for their winter popularity on the intensity of the sunshine by day, followed by crisp, cold nights.

Seasonal range. The seasonal range of temperature is affected by (1) latitude, (2) position with reference to land and sea, (3) prevailing winds, and (4) the presence of snow.

(1) The seasonal range of temperature increases with the latitude (compare Figs. 41 and 42, pp. 73 and 74), because the yearly variation of insolation increases with the latitude. San Diego and St. Paul (p. 72) are examples. In latitudes higher than that of St. Paul the range is still greater.

(2) Islands have a lesser range of temperature than continental lands in the same latitude, and coasts have a lesser range than interiors, because the range of sea temperature is less than the range of land temperature (Figs. 41 and 42). St. Louis and San Francisco (p. 72) are examples.

(3) A coast to which the prevailing winds blow from the ocean has a less range of temperature than a coast to which the prevailing winds blow from the land. Thus the range of temperature is less on the Pacific coast of the United States than on the Atlantic in the same latitude (Figs. 41 and 42), the winds being chiefly from the west in both cases. San Diego, Cal., with a range of 15°F., Yuma, Ariz., with 27°, and Savannah, Ga., with 34°, illustrate this effect.

(4) The presence of snow during the warm season, as in high latitudes and high mountains, prevents a high temperature, even though insolation is strong (p. 70). In the cold season, snow also tends to reduce the temperature of the lower air by reflecting a certain amount of insolation which might otherwise help to warm the land, and so the layers of air in contact with it. On the other hand, snow lessens the range of temperature of the soil beneath it, for snow checks radiation from the soil, and prevents it from being warmed by the direct rays of the sun. Unfrozen ground may exist under a heavy covering of snow, even though the air above the snow is far below the freezing point. By preventing alternate freezing and thawing of the soil, snow is important to many plants, as, for example, to winter wheat and clover.

Importance of temperature ranges. The annual range of temperature affects all industries connected with the soil. In general, the temperature of most importance to vegetation is the lowest or minimum temperature. For example, the palm-tree cannot grow where frosts occur; hence its distribution is limited to places where the lowest temperature of the year is above 32° F. Peach-trees, unless protected, are injured by protracted temperatures below —15° F.; and the frequent recurrence of such temperatures in winter prohibits the growth of peaches. For other plants, as corn, cotton, rice, tobacco, sugar cane, most fruits, and vegetables, the length of time without freezing temperatures (the *growing season*) is a critical factor.

Frosts during the growing season are, in some cases, so destructive as to amount almost to national disasters. A frost in the late spring, after corn is well started, or in early autumn, before it is ripe, may reduce the crop of good corn by millions of bushels. When freezing temperatures extend into regions usually free from them, they do great damage to fruit, as to orange groves in Florida. A disastrous frost in December, 1894, affected this region. Untimely frosts destroy not only tender crops for that year, but in some cases for years to come. Thus early in October (10–12), 1906, a temperature

which was in places 13° below freezing point killed hundreds of thousands of peach-trees in western Michigan. Peach-trees stand much lower temperatures in winter without injury, but this freezing temperature came before the trees were ready for it. A similar destruction of peach-trees occurred in parts of Ohio as a result of unseasonable cold early in December, 1910.

The seasonal range of temperature, or, more exactly, the temperature of winter, affects transportation. Navigation ceases early in winter (usually by December 15th), for example, on the Great Lakes, because ice forms about their borders and does not melt until after March 15th. Canal and river navigation amounts to little in middle latitudes from December to March, and many harbors, as that of Montreal, are blocked by ice for weeks at a time. The desire for a harbor free from ice in winter led the Russians to acquire Port Arthur, and helped to bring on the Russo-Japanese War, because Vladivostok, the port of Russia in Asia, is ice-blocked three to six months every winter.

Questions

1. From what sources, other than the sun, does the earth's surface receive heat?

2. Why does the earth get only about $\frac{1}{2000000000}$ part of the heat radiated by the sun?

3. Suggest a method of determining the actual points which are to be marked 212° and 32° on the tube of the Fahrenheit thermometer.

4. What temperature Centigrade corresponds to 45° F.? To −45° F.?

5. Make a rule for changing degrees F. to degrees C., and vice versa.

6. Suggest ways of obtaining the annual temperature of a place.

7. Enumerate the atmospheric conditions (all of them) under which most heat from the sun would reach the ground at a given place in the United States.

8. Enumerate the conditions (all of them) of land surface under which most heat from the sun would reach the ground at a given place in the United States.

9. The earth is probably not getting warmer, in spite of the fact that it is receiving heat continually from the sun. Why?

10. On June 21st, in latitude 40° N., which would receive more heat, (1) a horizontal surface, or (2) a vertical surface of equal area facing south? Which would receive more on December 21st? September 21st? Draw diagrams to illustrate answer.

11. For each of the various ways of heating a house, by (1) open fire, (2) stoves, (3) hot-air furnace, (4) steam, and (5) hot water, which process of heat distribution (radiation, convection, conduction) is most important?

12. In what way may satisfactory ventilation of a heated room be secured?

13. What conditions of the atmosphere at sea-level would cause the amount of heat it absorbs to vary?

14. Why does snow mixed with dirt melt more rapidly than clean snow?

15. How does a lake tend to modify the temperature of the surrounding land by day? By night? In summer? In winter? Explain each.

16. What effect would it have on the seasons, and on the products of middle latitudes (say 40°) if the earth's axis were inclined 33½° instead of 23½°? What would be the effect on seasons in the tropics?

17. Explain each important curve in the January isotherm of 10° F., northern hemisphere (Fig. 41).

18. (1) Compare and contrast the average January and July temperatures on the east and west coasts of the United States at the fortieth parallel (Figs. 41 and 42). (2) Explain the differences.

19. Why are the average annual temperatures over tropical lands higher than those over tropical seas?

20. Where do the highest July temperatures occur (Fig. 42)? Why there? The lowest January temperatures (Fig. 41)? Why?

21. Compare and contrast the seasonal range of temperature in the middle latitudes of the two hemispheres (Fig. 41 and 42). Why the difference?

22. Of two cities, St. Paul and Key West, one has an average daily range in temperature twice as great as the other. Which has the greater? Reasons?

23. Why is the average annual temperature higher in cities than in the surrounding country? Why is the daily range of temperature smaller in cities than in the country?

24. What is the length of the growing season in mountains, as compared with neighboring plains?

25. What conditions of air movement would you expect to find along the thermal equator?

26. On the equator, what altitude would have an average temperature of 32° in January? (Consult Fig. 41.) In July? (Fig. 42.) What would be the altitude for an average temperature of 32° in latitude 45° in January? In July?

27. Describe the probable changes of temperature in the different seasons for the places whose range of temperature is given on p. 72.

28. Why is frost less likely to occur on cloudy than on clear nights?

29. Suggest ways of protecting crops depending on this same principle.

30. What probably led to the early invention of the lamp by certain natives on the Arctic shores of North America?

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CHAPTER VI

CLIMATIC FACTORS: MOISTURE

Importance of Atmospheric Moisture

The atmosphere always contains water vapor, even in the desert, where the air seems driest. We cannot see or smell or feel water vapor, though air with much water vapor has a different feeling from air with little.

The presence of water vapor in the air may be proved in various ways. If a pitcher of ice-water stands in a warm room, drops of water may appear on the outside of it, and cold window panes often have "steam" on them in winter. In each case the water came from the air. Water vapor often condenses into water on the surface of dust particles in the air. Great numbers of these water-covered particles high in the air form clouds, from which rain may fall if the drops become heavy enough.

Water vapor is lighter than dry air; that is, a cubic foot of it weighs less than a cubic foot of dry air at the same temperature and under the same pressure. Water vapor in the air displaces some of the oxygen and nitrogen, and its presence therefore makes the air lighter.

The moisture of the atmosphere is no less important than oxygen and carbon dioxide to all animals and plants, for without it no life could exist on the land. It furnishes the rain and the snow which supply all springs and rivers, and it serves a most important function in connection with temperature, as already indicated, for it absorbs heat radiated from the sun and from the earth. It increases the average temperature at the bottom of the atmosphere, and reduces the extremes of heat and cold which would exist if the air were altogether dry. Its effect on temperature is shown by the fact that dry regions have greater ranges of temperature than moist ones in similar latitudes and altitudes. Moisture from the air also acts with the oxygen and with changes of temperature in the weathering of rocks and the formation of soil from them (p. 261).

Evaporation

Sources of water vapor. Water which is left standing in an open dish disappears slowly, and muddy roads and wet pavements become dry after the rain ceases. The water disappears in the form of *vapor*, which is water in particles too small to be seen. Vapor is passing from all moist surfaces into the air all the time. The change of liquid water into water vapor is *evaporation*. Evaporation also takes place from snow and ice, even though the temperature is far below that of melting, as shown by the slow disappearance of snow and ice, even when the temperature is below 32° F. Explorers in Arctic regions report that moist garments left on the snow during a clear night may be dry in the morning, even with a temperature of −40° F. The water in the garments freezes, and the ice evaporates.

All animals breathe out water vapor into the atmosphere. This is seen in winter when the water vapor of the breath condenses, and so becomes visible, in the cold atmosphere. The water breathed out into warm air is not seen because it does not condense. Plants also give out moisture, the amount, in many cases, being very great. Thus a thrifty sunflower plant, during its life of 140 days, gave off 125 pounds of water. Grass was found to give off its own weight of water every 24 hours, in hot weather. This meant, where the measurement was made, *6½ tons* per acre, or a little more than a ton for a lot 50 feet by 150 feet. A birch-tree, with some 200,000 leaves, was estimated to give off 700 to 900 pounds on a hot summer day, but much less on a cool day. Under certain conditions, wet ground, like wet meadow land, is made drier by planting trees which take up water from the soil and give it out to the air through their leaves. Attempts are being made in this way to improve conditions near Vera Cruz, Mexico. Water vapor also enters the air from all active volcanoes (p. 299). The oceans, however, are the great evaporating pans from which most water vapor comes, and but for them, the waters of the land would all be dried up in the course of time.

Water is in constant circulation in the air. The circuit which it makes is somewhat as follows: (1) It is evaporated from the ocean (and all moist surfaces); (2) as vapor, it is diffused or blown over the land, where some of it (3) is condensed and falls as rain or snow, feeding rivers, lakes, etc. A part of the rain which falls on the land

returns directly to the sea through rivers, a part sinks into the soil and rocks, and another part is evaporated again without flowing to the sea. The evaporation of water and the circulation of water vapor in the air are therefore important, not only for man, but for all living things. About half the water vapor of the air is below an altitude of 6,500 feet, and fully three-fourths of it below an altitude of 13,000 feet. The greater amount of water vapor in the lower part of the air, is one reason why the lower air is warmer than the upper air (p. 67).

On the average, 30 to 40 inches of rain fall each year on land; that is, enough to make a layer 30 to 40 inches in average depth if spread out over all the land. The amount of water evaporated from the oceans each year is about the same as that which falls from the air. If the *precipitation* (rainfall and snowfall) on the oceans is equal to that on the lands, square mile for square mile, and if all the water of the rain and snow came from the oceans and was not returned to them, the oceans would be dried up in 3,000 or 4,000 years. If an amount of water equal to all the rainfall of a year were evaporated from the lakes of the earth, they would probably be dried up in less than a year.

Rate of evaporation. Fig. 43 shows the estimated amount of evaporation which there would be per year from surfaces of lakes in various parts of the United States, if such bodies of water were present. Thus in Mississippi, if there were no rainfall or inflow, a surface of water would be lowered more than 50 inches in a year by evaporation; at New York, about 40 inches; at Milwaukee, about 30 inches; at Lake Superior, about 20 inches; at Denver, about 70 inches; and in southern Arizona, 90 to 100 inches. The greatest evaporation in the United States, so far as determined, is 101 inches per year, at Ft. Grant, Ariz.; the least, 18 inches, at Tatoosh Island, Wash.

By comparing these figures with the amounts of precipitation in different localities, it appears that the surface of a body of water having its level determined solely by precipitation and evaporation, would rise a few inches each year in Mississippi, would remain at about the same level at New York, and would be lowered seven or eight feet every year in Arizona. It is estimated that the lake called Salton Sea (southeastern California) will disappear by evaporation by 1925.

Several conditions affect the rate of evaporation. The principal ones are (1) the amount of water vapor already in the atmosphere,

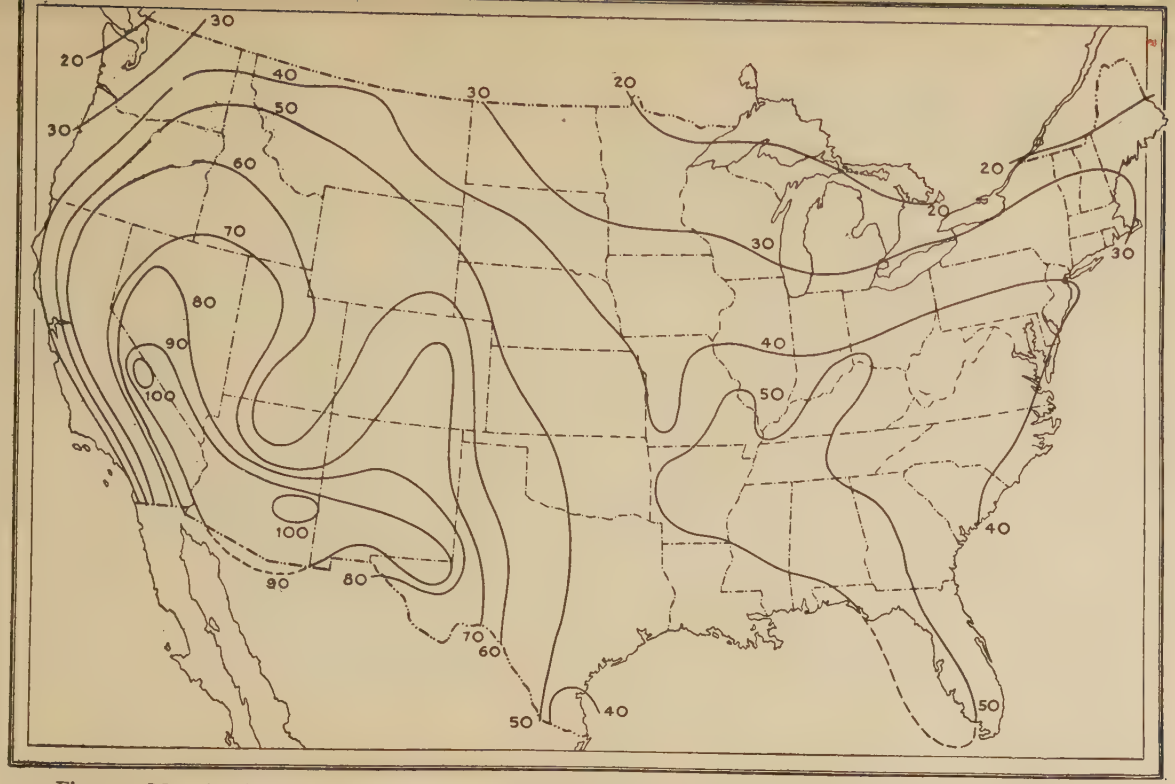

Fig. 43. Map showing the estimated amount of evaporation in the United States. The numbers on the lines show, in inches, the amount of water which would be evaporated each year if water were exposed freely. (Russell: Monthly Weather Review, Dec., 1904.)

(2) the temperature of the surface and the air over it, and (3) the strength of the wind. At a given temperature, *the less the water vapor in the air, the more rapid the evaporation from a water surface.* Raising the temperature of air from 30° to 50° F. doubles its capacity to hold water vapor, and hence increases the rate of evaporation. Air moving at the rate of 10 miles an hour will evaporate four times as much water as still air, other things being equal.

Effect of evaporation on temperature. Evaporation cools the surface from which it takes place. If the hand be moistened, it feels cool as the water on it evaporates, and the faster the evaporation, the more distinct the cooling. Moist clothing seems cooler in wind than in still air, even when the temperature is the same, because wind hastens evaporation. For the same reason, a day in summer when the wind is blowing seems cooler than a calm day when the temperature is the same. It takes about 1,000 times as much heat to evaporate a pound of water as it would take to raise its temperature 1° F. Evaporation from forested regions in moist tropical lands is so great that the temperature there is much lower than would be expected from the insolation. The slight evaporation from dry regions is one reason why they are so hot in the sunny days of summer. On the other hand, the increased evaporation from the human body in a dry region may reduce its temperature enough to make the heat less trying. It is a common thing to speak of dry heat as less uncomfortable than damp heat. The hot, dry air of a furnace room causes far less discomfort than the less hot, damp air of a greenhouse. On the other hand, moist air at 0° F. *seems* much cooler than dry air at the same temperature.

Evaporation and sensible temperature. Atmospheric moisture and evaporation, therefore, have much to do with the temperature as we feel it. The difference between temperature as it seems (*sensible temperature*), and temperature as it is (as shown by the thermometer) is often great. Thus observations in Death Valley, California, showed a maximum air temperature of 122° on five days, but the sensible temperatures (determined by a specially constructed instrument) ranged from 73° to 77° F. Similar observations for various parts of the United States show results as follows:

	Air Temp. July	Sensible Temp.	Difference
Boston (moist air)	72°	65°	7°
Savannah (moist air)	82°	75°	7°
Yuma (dry air)	92°	70°	22°

Thus Yuma does not seem so hot in summer as Savannah, and but little hotter than Boston. Sensible temperatures bear a very important relation to sunstroke and heat prostration, both of which are almost unknown in our dry southwestern states, but are of frequent occurrence along the less hot but moister eastern coast.

Evaporation and saturation. The amount of water vapor in the air varies greatly from place to place, and from time to time at the same place. When there is as much water vapor in the air as there can be under existing conditions, it is said to be *saturated*. Though we commonly say the *air* is saturated, yet it is, in reality, not the air, but the *space* which the air occupies which is saturated. The amount of water vapor necessary to saturate a given space depends on the temperature, and is nearly the same whether air is present or not. A cubic foot of air at 0° F. is capable of containing ½ grain of water vapor; at 30°, about 2 grains; at 60°, 5 grains; at 80°, 11 grains; and at 90°, nearly 15 grains. Thus the higher the temperature the greater the amount of water vapor necessary for saturation. Each increase of 20° in temperature about doubles the amount of water vapor a given space can hold.

Humidity

Absolute and relative humidity. The amount of moisture which the air contains is its *absolute humidity*. The percentage of moisture which air contains at any temperature, compared with what it might contain at that temperature, is its *relative humidity*. Thus if a cubic foot of air at 30° F. contains 2 grains of water vapor, it is saturated, and its relative humidity is 100 per cent. If the temperature is raised to 60° F., its capacity for water vapor is increased from 2 grains to 5 grains, and it then has only two-fifths the amount it could hold. Its relative humidity is therefore 40 per cent. Beneath such air, evaporation would take place rapidly from all moist surfaces, and the humidity would rise. On the other hand, if air at 80° F., containing 5 grains of water vapor (relative humidity about 46 per cent), were cooled to 60° F., the 5 grains would mean saturation for that temperature. Evaporation would then cease. Hence it appears that humidity and evaporation are related intimately, and that both depend on changes of temperature. These relations are of particular importance in connection with dew, fog, clouds, rain, and snow. They are also important to all land life.

Air is said to be "dry" when its relative humidity is low, and "moist" when its relative humidity is high. Thus 5 grains of water vapor in air at 90° F. means dry air (humidity 33), while the same quantity of water vapor in air at 60° F. means damp air. The air over damp England and that over the dry Sahara, for example, may have the same actual amount of water vapor per cubic foot.

Fig. 44 shows the average relative humidities throughout the United States, the range being from 80 along the coasts to less than 40 in some part of the southwest. Areas where the relative humidity is 35 or less are essentially desert, and areas where it is less than 50 are distinctly dry. In Death Valley, California, one of the driest places on earth, the average relative humidity for five months, when the record was kept, was 23; yet this *is but little less than the relative humidity of the air in the average furnace-heated house in winter.* The average relative humidity of air over the land is probably about 60; that over the ocean about 85. In that part of the United States which is productive, agriculturally, without irrigation, the relative humidity is, as a rule, more than 65. In high altitudes, relative humidity and sensible temperatures are both low, as a rule.

Importance of relative humidity. Corn, wheat, and rye, require, respectively, about 14, 10, and 8 inches of water during their growing seasons. If the total rainfall of a given place is 18 inches in that time, any one of the crops would seem to have enough. Practically, however, the relative humidity (and therefore the amount of evaporation) determines which of these crops may be grown with success. If the relative humidity is very low, rye only can be grown successfully, even with 18 inches of rain.

Relative humidity has important effects on the human body. The body is giving off moisture constantly, most of it being evaporated from the skin and lungs. High humidity checks evaporation, and this seems to be one cause of certain diseases in moist tropical regions. One such disease, *anæmia*, accounts for the characteristic tropical laziness. Low humidity increases evaporation from the body, and this is, on the whole, stimulating. It is believed by some that the excitable character of the people of some dry countries is due in part to this fact. Sudden changes from low to high humidity, especially when associated with sudden changes of temperature, such as occur when one goes out from a warm house in winter, probably favor diseases of the breathing organs (cold, etc.), so frequent at that season.

High relative humidity hastens the decay of food, especially meat; hence supplies of this food cannot be kept long in warm, moist regions. This is perhaps one reason why meat is little used in tropical countries. Unprotected iron wares rust rapidly in damp air; hence shipments of such wares to many tropical countries

Fig. 44. Map showing average annual humidity in the United States. (After U. S. Weather Bureau.)

require special packing to prevent injury in transit. The damp air of the coast of Maine prevented the successful development of the sardine industry, in spite of a law providing that the drying should be done only on "dry clear days," until a special method of curing the fish made it possible to compete with the French product dried out of doors. Low humidity permits salt making by natural evaporation in Mediterranean countries. In some places meat is dried in the air, giving the so-called "jerked beef," and even "burial" of the dead may be on high platforms in regions where dry air quickly mummifies the body.

Extreme dryness and the evaporation which goes with it cause wood to shrink, warp, and crack to such an extent that boxes which were strong fall apart. Goods to be shipped far through a very dry region need special preparation, and even railroad cars have to be of steel to withstand the effect of desert dryness. Humidity is so important in textile industries, as in spinning cotton, that the early centers of cotton manufacture tended to develop in damp regions. In the best mills, special devices are now used to maintain uniform humidity.

Dew point. As already stated, saturation may be produced by cooling the air. If saturated air is cooled, some of its water vapor is *condensed* (formed into liquid). The temperature at which the water vapor of the air begins to condense is the dew point. Saturated air is therefore at the dew point. Air may be brought to the dew point in various ways: (1) It may be blown where the temperature is lower, as to a higher latitude or altitude; (2) it may be cooled by having cooler air brought to it, as by a cold wind; (3) it may be cooled by radiation, or (4) by expansion, as when it rises.

The temperature of the dew point is not fixed, but is influenced by the amount of water vapor in the air, as already explained (p. 89). If air at 80° F. contains 5 grains of water per cubic foot, its dew point will be reached when it is cooled to 60° F.; but if the amount of water vapor in air at 80° F. is only 2 grains per cubic foot, the dew point would not be reached until it had been cooled to 30° F.

If the temperature of condensation is above 32°, the vapor condenses into liquid water, which at first takes the form of droplets, such as those of which fog is made. If the temperature of condensation is less than 32°, particles of ice form as the vapor condenses. They may be the beginnings of snowflakes, or they may be particles of frost. The condensation of water vapor sets free an amount of heat equal to that absorbed in its evaporation. This heat checks the cooling, a fact of significance where the temperature of condensation is near 32° F., and where continued cooling would bring the temperature to the freezing point.

Dew and frost. In the clear, still nights of summer and autumn, the temperature of the surface of the land, cooling by radiation,

often becomes lower than the dew point of the air above. Moisture then condenses on the surface. Such moisture is *dew* if the temperature of condensation is above 32°. The water which condenses on the outside of a pitcher of ice-water (p. 84) is dew, just as much as that which forms on grass blades. Dew does not fall, but *condenses* on the surface of solid objects. Dew is more likely to form on still nights than on windy ones, because wind tends to move away air which is approaching its dew point, supplying other air in its place, and the incoming air may be warmer or drier than that which moved on. Dew is more likely to form on clear nights than on cloudy ones, because radiation and cooling are greater when there are no clouds. This association of dew with clear skies led the ancients to believe that dew came from the stars. It was, therefore, thought to be possessed of important curative properties. When the temperature of the dew point is below 32° F., the moisture which condenses on solid objects condenses as ice particles, or *frost*, instead of dew.

Dew, and sometimes frost, may form on the under sides of objects. If a pan is placed bottom up on the ground, there may be dew on the inside of it in the morning. There is often dew on the under side of a flat stone when there is none on its top. This may be true even in a desert. The explanation is as follows: The air in the ground has some moisture, and during the day, when the sun shines, this air is warmed. At night the air above cools much more quickly than that in the ground. The cooler, heavier air above then sinks into the ground, crowding up the warmer air below with its water vapor. On reaching the cool pan, or other object, some of the moisture is condensed. In the day-time the rising moisture does not condense on the pan, because the pan is warmer than the water vapor below, especially if the sun is shining. The water vapor in the soil also diffuses upward, even when not crowded up by the sinking of heavier air. It thus appears that part of the moisture forming dew comes from the soil. Laboratory experiments have shown that some of it comes from the vegetation itself. The moisture of the air, however, is the great source of dew.

In most places dew is rather unimportant, because the amount of moisture so condensed is small. It is difficult to measure the amount of dew, partly because it evaporates so quickly in the morning, and partly because the color and composition of the object on which it accumulates play an important part in influencing the amount. In some places, as in certain tropical districts, the amount of dew is great ($\frac{1}{10}$ inch per night in some cases) and serves much like a light rain in supplying moisture to vegetation.

Fog and cloud. The condensing of water vapor in the air into droplets makes *fog* (Fig. 45) if the condensation takes place in the lower part of the atmosphere at a temperature above 32° F. It makes ice particles, or frost, if the temperature is below 32° F. The

water droplets and ice particles take the form of *clouds* if the condensation takes place above the bottom of the atmosphere (Figs. 46-49). Fog and frost particles in the lower air are the same as clouds, except that clouds are higher. Fog may be said to be cloud resting on the surface of the land. If moisture condenses and the particles remain suspended in the air above the top of a mountain, there is, to the observer on the plain or in the valley below, a cloud about the moun-

Fig. 45. Fog over the lowlands, as seen from Mount Wilson, California. (Ellerman.)

tain; but if the observer were to climb up into the cloud, it would then appear as fog. Fogs are formed in many cases where the moist air over warmer water (e.g., a warm ocean current) blows over a colder surface of water or land. The droplets of water forming fog and cloud are very small, many of them not more than $\frac{1}{3000}$ of an inch in diameter. Though they are always tending to sink, they are so small that the gentlest currents of rising air are sufficient to keep them up.

Fogs often form in valleys at night (Fig. 45), especially in autumn, when the night temperatures are much lower than those of the day. The cooler air settles in the valleys, and the air there is more likely to be brought to the dew point than that over the uplands. Fogs occur more frequently in large cities than in the nearby country, apparently because the large numbers of solid particles poured into the

air in the form of smoke favor condensation. In London the increase in coal consumption was accompained by increased fogs until the "smoke nuisance" was partly stopped; then the fogs decreased. In other places, also, doing away with smoke has practically put an end to fogs.

The composition of city fog may be judged from the calculation that in a year the amount of solid matter (mainly soot) deposited from fogs in London amounted to six tons per acre. A three days fog in Manchester, England, was calculated to deposit 150 pounds of sulphuric acid per square mile. The shutting off of sunlight from London by fogs probably means, for the whole city, an expense of at least $5,000,000 a year for extra gas. A dense fog in London, which lasted from December 10 to 17, 1905, was estimated to have cost the city $1,750,000 per day, in one way and another, largely through suspension of business. Such estimates are, however, to be taken with reserve, since much of the suspended business is transacted later. City fogs are generally injurious to health, and long continued fogs may cause a distinct increase in the death rate.

Fogs interfere with all kinds of traffic; they are the most common cause of disasters at sea, as in the collision of the French steamship La Burgogne with an iceberg, in the North Atlantic, as a result of which more than 600 lives were lost. Coastwise traffic, as in Nantucket Sound, or traffic in river harbors, as at Philadelphia, is kept at a standstill for days at a time by fogs. Fogs are also a common cause of railway accidents. So harmful are fogs in these ways, that elaborate experiments have been made to dispel them in railway yards and in front of vessels. Various devices, using heated air to evaporate the fog, or electrical discharges to make it fall, have been tried. Some of them have succeeded in clearing the air for spaces of 50 to 200 yards in front of the apparatus.

In some places where fogs are frequent and heavy, they are an important source of moisture. The distribution of the redwood tree in California corresponds closely to the zone over which fogs extend inland. Along some African rivers the moisture from valley fogs, always drifted one way by the winds, causes heavier vegetation on one bank than on the other. Attempts by men to utilize the moisture of fogs have never proved very successful.

Clouds and fogs affect temperature by hindering radiation. A cloudy night is not generally so cold as a clear one. Cloud and fog during the day-time hinder the usual daily rise of temperature, by shutting out the sun's heat. In general, cloudiness lowers the summer temperature of middle latitudes, and raises the winter temperature. Heavy fogs have had an influence in war. Thus a fog helped Washington in his retreat to New York, after the battle of Long Island.

Forms of clouds. Clouds take many forms. Among the more common are the *cumulus*, the *stratus*, the *nimbus*, and the *cirrus* clouds.

Cumulus clouds are thick, and their upper surfaces are somewhat dome-shaped, with irregular and fleecy projections. Their bases are nearly horizontal (Fig. 46). They are formed from the water vapor

in ascending convection currents, and their level bottoms seem to mark the altitude at which condensation takes place as the air rises. Their bottoms are usually somewhere from 1,800 to 4,000 feet above the land, but the tops may rise three or four miles higher. They appear, especially in clear, hot weather, in mid- or late-forenoon, after

Fig. 46.

Fig. 47.

Fig. 48.

Fig. 49.

Fig. 46. Cumulus clouds. (Cloud chart, Hydrographic Office, Dept. of Navy.)

Fig. 47. Cumulo-nimbus clouds. (Cloud Chart, Hydrographic Office, Dept. of Navy.)

Fig. 48. Cirrus clouds. (Cloud Chart, Hydrographic Office, Dept. of Navy.)

Fig. 49. Cirro-stratus clouds. (Cloud Chart, Hydrographic Office, Dept. of Navy.)

insolation has established convection currents. They attain their greatest size at about the hour of maximum heat. As evening approaches they commonly grow smaller.

Stratus clouds are horizontal sheets of cloud, often not more than 1,000 feet above the earth.

Nimbus or *rain clouds* (Fig. 47) consist of thick masses of dark clouds without definite shape and with ragged edges, from which continued rain or snow generally falls. Nimbus clouds are rarely more than half a mile above the earth's surface.

Cirrus clouds are delicate, fibrous, or feathery (Fig. 48). They are generally white, and sometimes arranged in belts. They are usually high, five miles or more, and thin, and probably always consist of particles of snow or ice.

Between these types of clouds there are many gradations of which perhaps the most interesting is the *cirro-stratus* (Fig. 49), a thin, veil-like cloud, almost imperceptible, usually extending in a sheet over a large part of the sky.

When rays of light from the sun or moon pass through the ice particles of which the cloud is made, the rays are turned aside (*refracted*), and cause a ring, or halo, around the sun or moon. Popular belief in many places makes the halo a sign of coming storm, a belief which has some foundation in fact, because cirro-stratus clouds usually are associated with general storm areas.

In general, cirrus and cumulus clouds are fair-weather clouds, and do not give precipitation. The latter, however, may grow into the cumulo-nimbus or summer thunder cloud, losing its fleecy whiteness, and produce rain. Cirro-stratus, stratus, and nimbus clouds are more likely to be foul-weather clouds.

Cloudiness and sunshine. The chief importance of clouds is found in their relation to (1) precipitation; and (2) sunshine. Clouds cut off sunshine (Fig. 50) and reduce the amount of insolation; hence they lower day-time temperatures. Clouds also check radiation, and so tend to keep night temperatures higher, which means less likelihood of frost when the temperature is near the freezing point. Cloudy localities, therefore, have less variable temperatures than clear ones. Through their effect on temperatures, clouds also affect humidity and evaporation, raising humidity and lowering evaporation. Hence cloudy localities are generally cool and damp; as a result, the types of vegetation and the crops grown there are different from those of places in the same latitude where clouds are few. Thus vineyards are rarely found in cloudy regions, wine production being typical of sunny countries.

In general, great cloudiness goes with great relative humidity (Figs. 44 and 50). Thus cloudiness is somewhat greater in winter than in summer, greater in higher latitudes than in low ones, and

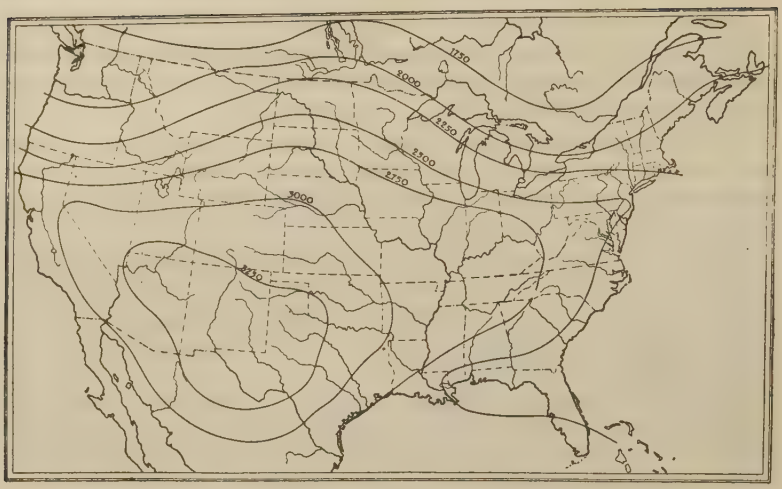

Fig. 50. Map showing mean annual number of hours of sunshine in the United States. (After Van Bebber.)

greater along sea-coasts than in continental interiors. The sunniest parts of the earth are hot deserts.

The matter of hours of sunshine is also important in connection with the using of the direct heat of the sun as a source of power. In many dry countries, where fuel is scarce, it is customary, when hot water is needed, to expose it to the direct rays of the sun in a black vessel. The temperature of water may be raised, in this way, as high as 140° F., after which less fuel is necessary to boil it. Acting on this principle, various devices have been invented to gather the heat from a large area and concentrate it for the purpose of generating steam for an engine. From the actual operation of solar engines it appears that the amount of heat from 100 square feet of surface will give one horse power for 8 or 9 hours a day. Calculated on this basis, a small part of the sunny section of Arizona would yield many times as much power as is used in the entire country at present. This source of power may be a great asset in the distant future.

Precipitation. The condensation of the water vapor of the air leads to rain, snow, or hail, if the products of condensation fall. Whether precipitation really takes place after the formation of clouds, depends on many conditions. To give rain or snow, the particles of water or snow in the cloud must be large enough to fall. Drops of rain vary in diameter from $^1/_{50}$ to $^1/_5$ of an inch. If they are to reach the ground they must not pass through air which is dry enough and warm enough to evaporate them before they reach the bottom of the

atmosphere. In desert regions, water may sometimes be seen to be falling from a high cloud, when not a drop reaches the ground. The falling drops evaporate as they descend.

Precipitation and evaporation. The *distribution of rainfall* depends, in large measure, on the winds, and will be considered later. The amount and distribution of precipitation, as they concern plant life, however, are connected intimately with the amount of evaporation. Thus two localities which have the same rainfall may have very different sorts of plants, because more of the precipitation in one place returns quickly to the atmosphere through evaporation.

In some parts of western Texas, with a precipitation of 22 inches, there is moisture enough for various kinds of hardy grasses and for "*dry-farming*" (p. 498), yet the region is given over largely to grazing. In the valley of the Red River in Minnesota and North Dakota the precipitation is a little less; yet this is one of the most important wheat regions of the world. The difference between the two regions is due chiefly to the fact that evaporation is about 2½ times as great in Texas as in the Red River Valley, because of the higher temperature in the former place.

In many other localities where rainfall is scanty, evaporation is one of the most important of all climatic factors, so far as vegetation is concerned. Dry-farming depends partly on the principle that if evaporation from the soil is checked, even scanty rainfall (15 inches yearly) may suffice for hardy crops like wheat. In many parts of the West, also, rows of trees are planted or high fences built to act as wind breaks, and to check evaporation from gardens. The so-called "hot winds" which sometimes do great damage to the corn crop, as in Kansas and Nebraska, owe their destructiveness chiefly to the rapid evaporation caused by their high temperature and extreme dryness. If these winds were moist, their temperature would not hurt the corn. Desert plants have peculiar characteristics, as fleshy leaves and smooth, shining surfaces, developed apparently with reference to preventing loss of moisture by evaporation.

Artificial Condensation

From a desire to increase the rainfall of arid regions, or relieve droughts in other sections, various attempts have been made to produce rainfall. The methods tried have been various, but the results have all been failures. The plan most tried has been that of producing explosions of some sort in the air well above the land. One reason for trying this method was found in the popular belief that great battles, with much cannonading, are followed by rain. So far as the belief in rain after battles is well founded, it is probably to be explained in some other way. Man has not yet succeeded in producing rain on any important scale, and is not likely to. If there were many cloud particles in the air, the jar of an explosion might

perhaps cause them to unite, and so make them large enough to fall; but the amount of rainfall which can be thus produced, under the most favorable conditions, is probably too small to be of consequence. The other methods which have been tried or suggested seem equally useless.

Questions

1. What are the results of the fact that evaporation is faster at Denver than at Milwaukee?
2. Why is the crop in a grain field poor around the base of a tree?
3. Why does wind increase the rate of evaporation?
4. Where, in middle latitudes, would you expect the sensible temperature to be highest in summer? In winter? The same for tropical regions.
5. What is the effect on sensible temperatures of the relative humidity which prevails in houses in winter?
6. Why is the humidity in houses in winter different from that out of doors, even where the furnace has a supply pipe taking in outside air?
7. What is the effect of the indoor winter humidity on the amount of fuel burned?
8. Beds of rock salt are found underground in some places. What conclusion may be drawn as to the climate when the deposit was formed?
9. Why does fog in the evening appear first close to the ground?
10. Why are clouds rarely formed above an altitude of 10 miles?
11. Why does most of the heavy precipitation come from low clouds?
12. In what parts of middle latitudes might the sun's heat be regarded as a possible source of power? In what parts not? Why?
13. What is the reason for the formation of more dew on surfaces of stone or metal than on pieces of wood near by?
14. Explain the fact that the lower leaves or branches of a plant may be nipped by frost, when the upper parts of the same plant are unaffected.
15. Why are frosts less common after heavy rain than at other times?
16. Why does a covering of newspapers or of thin cloth often protect plants from frost?
17. Suggest other means by which protection from frost might be secured for large fruit orchards and truck farms.
18. In what ways may plants in a house be beneficial to the air?
19. At what time of day is humidity lowest, on the average? Why?
20. Why does high humidity in summer tend to make the air feel warmer, and in winter make it feel colder?
21. Explain the distribution of sunshine as shown in Fig. 50.

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CHAPTER VII

CLIMATIC FACTORS: PRESSURE AND WIND

Pressure

Importance of pressure. The downward pressure (or weight) of the air is about 15 pounds to the square inch at sea-level. The pressure varies a little from time to time at any given place, and is rarely the same at any two places more than a few miles apart. In themselves, variations of pressure have little effect on life; but the variations have much to do with winds and other elements of weather, and weather is most important to life. Hence it is desirable to have some simple method of measuring and recording atmospheric pressures. The instrument by which the pressure of the atmosphere is measured is the *barometer.*

Fig. 51. Diagram to illustrate the principle of the barometer. The pressure of the air at *A* maintains the mercury at *B* in the tube when there is no air in the tube above *B*.

The barometer. The principle of the barometer is as follows: A tube more than 30 inches long, closed at one end, is filled with mercury. The open end of the tube is then placed in a dish of mercury (Fig. 51). The mercury in the tube will sink until its upper surface reaches a level about 30 inches above the level of the mercury in the dish, if the place of the experiment is at sea-level. The mercury remains at this level in the tube, because the pressure of the air on the mercury in the dish is enough to balance the weight of the mercury in the tube. Since the pressure of the air at sea-level balances a column of mercury about 30 inches high, the pressure of the air at sea-level is said to be 30 inches (or 760 millimeters). If the pressure is more than 30 inches it is said to be *high;* if less than 30 inches, it is said to be *low.* At sea-level the

variation above and below 30 inches is rarely more than one inch. Changes of pressure with changing altitudes are much greater.

Pressure and altitude. At elevations above sea-level the pressure grows less, as shown in the following table:

Altitude Above Sea-Level, in Feet	Normal Barometric Pressure, in Inches
0, as at New York	30
1,800, as at Spokane, Washington	28
3,800, as at El Paso, Texas	26
5,900, as at Colorado Springs, Colorado	24
8,200, as at Bogotá, Colombia	22
10,600, as at Leadville, Colorado	20
16,000, as at St. Vincente, Bolivia	17

At an altitude of six miles, a little above the highest point of land, the pressure is less than one-fourth the normal for sea-level.

The rate of decrease of pressure with increasing height being known, the altitude of a place above sea-level may be measured by means of the barometer. A special form of barometer, the *aneroid barometer* (Fig. 52), has been devised for this purpose.

The pressure at 10,600 feet, approximately two miles, is about 10 pounds to the square inch. As a result, water passes more readily into steam when heated; hence its boiling temperature is lower with decreased pressure. Pressure and boiling temperature bear a nearly constant ratio to each other — the boiling point being lowered about 1° F. for each 550 feet of altitude, or for every 0.589 inch of barometric fall. This principle may, therefore, be used to determine heights above sea-level. Thus on top of Pike's Peak, water boils at about 186° F. or 26° below the boiling temperature at sea-level (212°); its altitude therefore is a little over 14,000 feet.

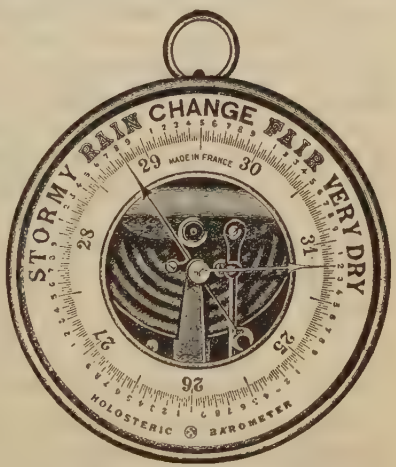


Fig. 52. Aneroid barometer. The needle moves to the right as the atmospheric pressure increases, and to the left as it decreases.

Such a condition makes cooking by boiling very difficult or impossible at high altitudes. Thus for Leadville, more than 10,000 feet above sea-level, many of the cooking recipes of Chicago or New York would be unsuccessful unless allowance were made for the lower boiling point. The decrease of pressure explains some of the discomforts, such as mountain sickness, experienced by many mountain climbers. Bleeding from the nose, nausea, and headache, the most common effects, are due to the fact that the blood pressure in the body is adjusted to the atmospheric pressure at lower altitudes, and does not readjust itself quickly enough to the changing conditions as one ascends, especially if the ascent is rapid. After a short stay at relatively high altitudes, these discomforts disappear in most cases. An analogous effect is produced on workers in high-pressure air-chambers (caissons), such as are used in laying foundations for bridge piers. Not infrequently the men work under an air pressure three or four times the normal at sea-level. Coming too quickly from the caissons into the open air, men are in some cases stricken with the dread *caisson disease*, which usually proves fatal in a few hours. Deaths as the result of unwise ascents to high altitudes are not unknown, but in most cases they are due not so much to lower pressure, as to weakness of the heart, and its need for greater activity on account of diminished supply of oxygen.

Distribution of pressure. The pressure of the atmosphere at sea-level varies from point to point, and from time to time at the same point. Some of the reasons are as follows:

(1) The temperature of the surface on which the air rests is unequal, and increase of temperature makes the air lighter. As the temperature varies, the pressure varies.

(2) Water vapor in the air makes the air lighter because it displaces some of the oxygen, nitrogen, and other constituents which weigh more than the vapor. The amount of moisture in the air is greater in warm regions (but not in hot deserts) than in cold ones, and greater over moist surfaces than over dry ones. Since the amount of moisture in the air varies from time to time, the pressure is constantly changing.

Representation of Pressure on Maps and Charts

Isobars. For convenience in the study of pressure distribution, lines may be drawn on maps connecting points where the atmospheric pressure is the same, analogous to the lines connecting points having the same temperatures. Such equal-pressure lines are *isobars*. A map showing lines of equal pressure is known as an *isobaric map* or *chart*. An isobaric chart for the year shows isobars connecting points having the same *average pressure* throughout the year. There may be isobaric charts for a season, for a month, or for shorter periods. The daily weather maps are daily isobaric charts. Fig. 53 represents

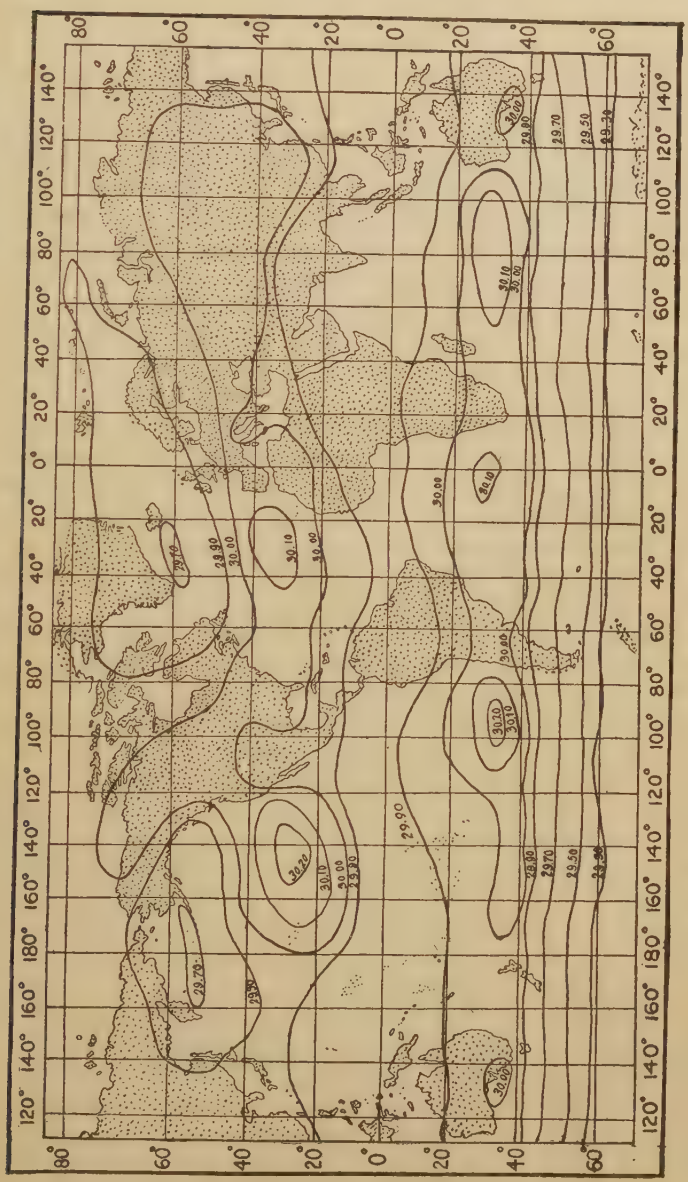


Fig. 53. Chart of mean annual isobars. (After Buchan.)

an isobaric chart for the year. The figures on the lines indicate the average pressure for the year in inches.

In the southern hemisphere, the isobar of 30 inches encloses a belt extending almost around the earth, being interrupted only in the vicinity of Australia. Every point within the area enclosed by this isobar has an average atmospheric pressure of more than 30 inches. Every point within the isobar of 30.10 inches has an average annual pressure of more than 30.10 inches, while every point between the isobars of 30 and 30.10 has an average annual pressure of more than 30 and less than 30.10 inches, etc. Between the two adjacent isobars of 29.90 in the equatorial part of the Atlantic, the pressure is, on the average, less than 29.90, but not so low as 29.80. If the pressure sank to the latter figure, there would have been isobars of 29.80 inches.

It will be remembered that in the case of the temperatures shown on an isothermal chart allowance is made for altitude above sea-level. In the same way, the pressures shown on land on an isobaric chart are those which would exist if there were no elevations above sea-level. The allowance for altitude is not a constant figure, but varies with the temperature and the pressure. For low altitudes the pressure decreases about .1 inch for each 90 feet of rise.

Relation of isobaric surfaces and air movement. An *isobaric surface* connects places having the same air pressure. If, for example, one place at sea-level has a pressure of 30 inches, and another a pressure of 30.10 inches, the isobaric surface of 30 inches is above sea-level at the place where the pressure is 30.10 at sea-level. If the pressure at sea-level at another place is 29.90 inches, the isobaric surface of 30 inches is below sea-level there. An isobaric surface, therefore, may have slopes.

Fig. 54 shows a series of isobars, with the pressure least at the center, and Fig. 55 shows the slope of the isobaric surfaces in the same area. Fig. 56 shows another series of isobaric lines, with the pressure greatest at the center, and Fig. 57 shows the slope of the isobaric surfaces in the same region.

If a surface of water had the form shown by the uppermost line in Fig. 55, the water would flow in from all sides until the surface became level. If the water surface had the form shown in Fig. 57, the water would flow away from the top in all directions. The air, which is more fluid than water, acts in a similar way, and moves down the slope of any isobaric surface. Such movements of air are *winds*.

From these figures it may be seen that wind blows *toward* areas of low pressure, and *from* areas of high pressure. When the isobaric slope (or *isobaric gradient*) is high, the wind is strong; when the isobaric gradient is low, the wind is gentle; and when there is no isobaric gradient, that is, when the isobaric surface is level, there is no wind. The strong wind is strong for much the same reason that a swift river is swift; the gentle wind is gentle for much the same reason that the slow river is sluggish; while the absence of wind may be compared to the pond in which there is no perceptible current, because there is no slope of the surface.

Courses of isobars. Returning now to Fig. 53, several points are readily seen: (1) The isobars have a general east-west course, though many of them are not straight; (2) on the average, they show greater pressure in low latitudes than in high latitudes; (3) they are

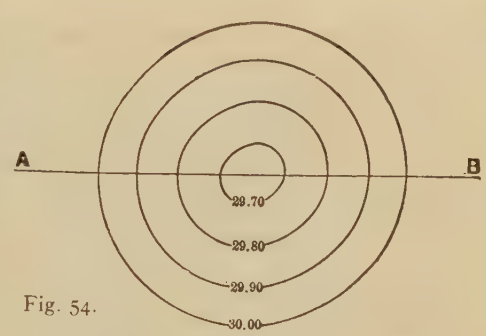
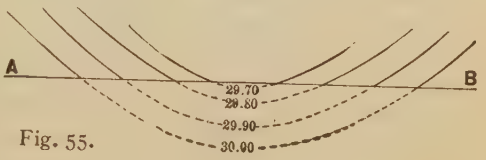


Fig. 54.



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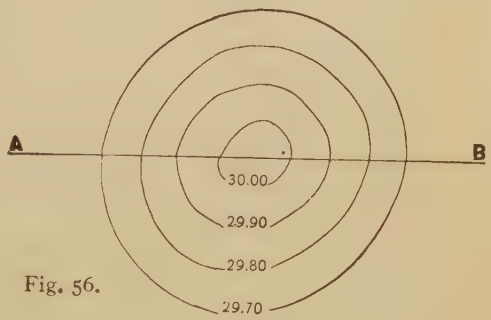

Fig. 56.

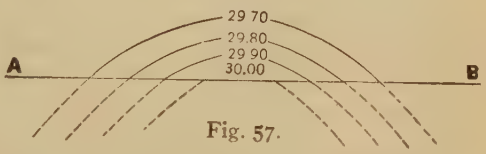

Fig. 57.

Fig. 54. A series of isobaric lines showing decreasing pressure toward the center.

Fig. 55. Section through Fig. 54, showing the slope of isobaric surfaces. It will be seen that *isobaric lines* are the lines where *isobaric surfaces* cut sea-level.

Fig. 56. A series of isobaric lines showing increasing pressure toward the center.

Fig. 57. Section through Fig. 56, showing the slope of isobaric surfaces.

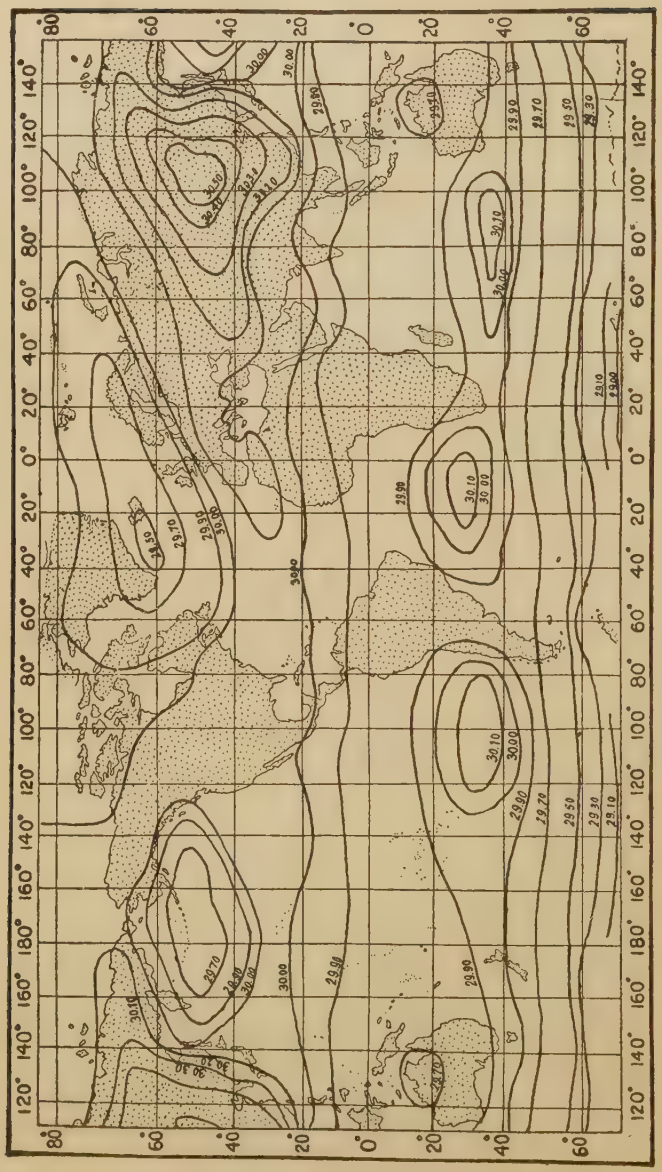

Fig. 58. Chart of isobaric lines for January. (After Buchan.)

highest (that is, they show highest pressures) in the latitudes just outside the tropics; (4) they are more regular in the southern hemisphere than in the northern; and (5) they are, on the whole, more regular on the sea than on the land.

The isobaric map for January (Fig. 58) shows also that a high-pressure belt is very wide in the northern hemisphere, especially on the land, which at this season (winter) is cooler than the sea. This fact suggests that high pressure goes with low temperature. In the southern hemisphere, January is a summer month, and the land is warmer than the sea. If high temperature causes low pressure, the pressure in the southern hemisphere at this time should be less than that in the northern, and it should be lower on the land than on the sea. The map shows that both these things are true. This chart, therefore, seems to show that high temperature reduces pressure.

A study of the isobaric chart for July (Fig. 59) leads to the same conclusion. At that time of year, the pressure in the southern hemisphere (winter) should be higher, on the average, than in January (Fig. 58); especially should it be higher on land, as the map shows it to be. In the northern hemisphere in July, on the other hand, the pressure should be less than it was in January, and especially should it be less on land, which is much warmer than it was in winter. Fig. 59 shows both these things to be true. We have confidence, therefore, in the conclusion that high temperature reduces the pressure, while low temperature increases it. The charts furnish other evidences in support of the same conclusions.

If temperature alone controlled pressures, they should be lowest near the equator, where it is warmest, and highest near the poles, where it is coldest. Fig. 53 shows that the average annual pressures are distributed in apparent disregard of temperature, for the pressures are highest neither where it is coldest nor where it is warmest. It is clear, therefore, that neither temperature nor latitude entirely controls the distribution of pressure.

Isobars and humidity. We have seen (p. 104) that water vapor makes the air lighter. But the isobars are not lowest over the oceans in warm latitudes, where the air contains, on the average, most moisture. We conclude, therefore, that the amount of moisture in the air is not the chief factor controlling the isobars.

Inequalities of temperature and moisture in the air are the only factors thus far studied which might affect the isobars; and since they do not explain the most striking feature in the distribution of

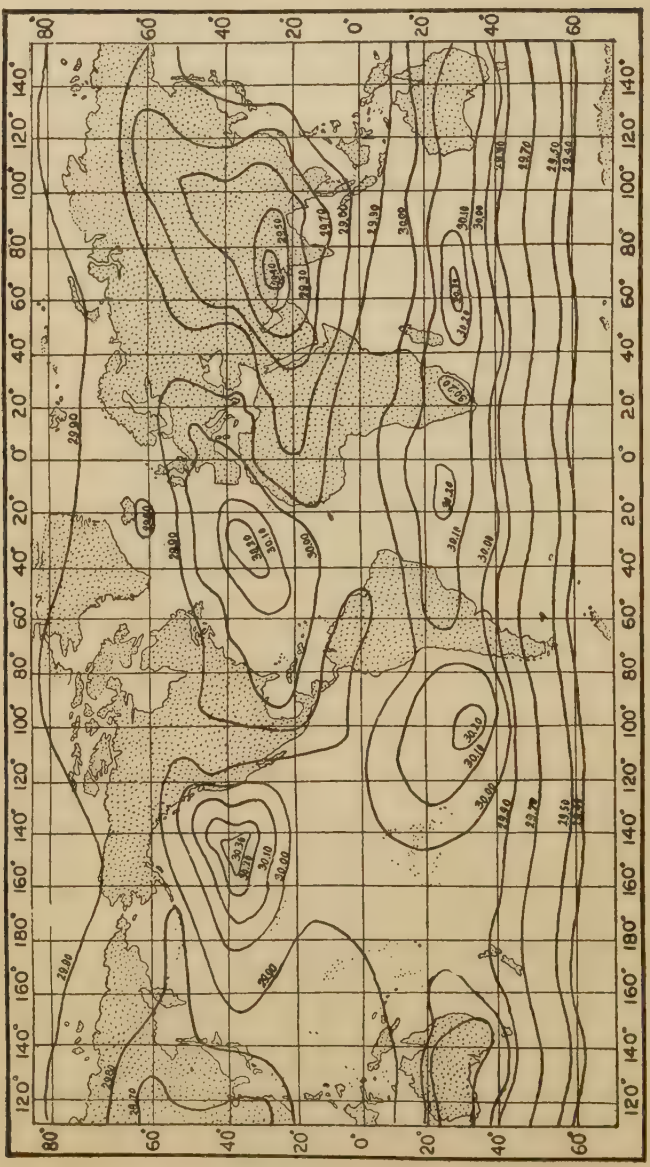

Fig. 59. Chart of isobaric lines for July. (After Buchan.)

atmospheric pressure, namely, the high pressures in relatively low latitudes, we conclude that something besides temperature and moisture must be involved in their explanation.

The high-pressure belts. The explanation of the high pressure in low latitudes, rather than in high, and the explanation of the highest pressures just outside the tropics, are not found on the isobaric charts. These larger features of pressure-distribution are to be explained by the general circulation of the atmosphere under the influence of rotation (p. 112).

Winds

Importance. Horizontal movements of the air are *winds*. Winds are important in many ways, as in carrying away the impurities of city air, in spreading dust and sand (p. 313), in erosion (p. 314), in furnishing power for windmills and sailing vessels, in increasing evaporation (p. 88), and in distributing the moisture of the air. Winds also affect human beings directly, for they lower the sensible temperature, and are, as a rule, stimulating and invigorating, while calm air (if warm) is enervating. In all these ways the fact of air movement is important.

Winds are produced by inequalities of pressure at the same level. These inequalities are being renewed constantly by unequal heating, and in other ways; hence winds are always blowing, and there is a general circulation of the atmosphere from regions of greater pressure to those of less pressure at the same level.

Relation of winds to the distribution of insolation. If the air over the whole earth were quiet at a uniform low temperature, and if it could then be heated by the sun for a time without any

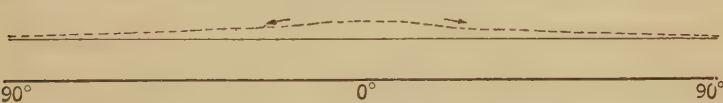

Fig. 60. The lower line may be taken to represent the surface of the earth; the upper solid line, the outer surface of the atmosphere as it would be if the temperature were everywhere equal. The dotted line shows the effect of heating on the surface of the air. Movement would result as indicated by the arrows.

horizontal movement, the effect would be to raise its surface everywhere, and to raise it most where it was heated most, that is, in low latitudes (Fig. 60). Under these conditions there would be a barometric slope from low latitudes toward high latitudes. *Before*

horizontal movement began, there would be no change of pressure at the bottom of the air, for the same amount (mass) of air would lie over each place, as before the heating. But if the surface of the air had the form shown by the dotted line in Fig. 60, the upper air would move as shown by the arrows. Since the air in low latitudes is always warmer than that in high latitudes, the upper air should always be moving from the equatorial zone toward the polar zones in both hemispheres. These poleward movements of the upper air lessen the pressure at the bottom of the atmosphere in low latitudes, because air has moved away from them. *After air has moved from the equatorial region toward the poles* (Fig. 60), there is more air over a given spot in high latitudes than in low. A barometric gradient is thus established *toward the equator at the bottom of the atmosphere.* Air then moves from higher latitudes to lower latitudes at the bottom of the air (Fig. 61).

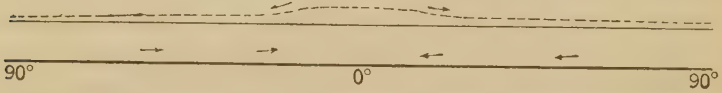

Fig. 61. The movement of air indicated in Fig. 60 would result in further movement as shown by the lower arrows in this figure.

Here, then, we have the elements of a general circulation, a poleward movement in the upper air, and an equatorward movement in the lower air, and the unequal heating which generates these movements is in operation all the time.

If the earth did not rotate, these movements of air would tend to follow meridians. The poleward-moving air would blow north in the northern hemisphere, and south in the southern, while the air moving toward the equator would blow south in the northern hemisphere, and north in the southern. Rotation, however, turns the air currents to the right in the northern hemisphere, and to the left in the southern.

Effect of the extra-tropical belts of high pressure. Let us now note the effect of the high-pressure belts just outside the tropics (Fig. 53) on the circulation of the air. From these belts the air flows to areas of lower pressure on either side, at the bottom of the atmosphere, giving rise to distinct wind zones.

Wind zones. The winds blowing poleward from the high-pressure belts are turned toward the east in both hemispheres, and

so become *westerly winds* (southwesterly in the northern hemisphere, and northwesterly in the southern). The winds blowing from the belts of high pressure toward the equator become *easterly winds* (northeasterly in the northern hemisphere, and southeasterly in the southern), and are known as *trade-winds* (Fig. 62). Sailing west from the Canary Islands to find Asia, Columbus came under the influence of the trade-winds, which bore him steadily across the Atlantic. Thereafter, many seamen from Europe followed this course. The zone along the thermal equator, where the northeasterly and southeasterly trades meet, and where rising currents of air are stronger than horizontal movements, is known as the *zone of equatorial calms*, or "*doldrums*," a region dreaded by the crews of sailing vessels, as much as the trade-winds were welcomed. The position of this zone of calms shifts a little with the sun, its center remaining near the thermal equator (Fig. 95).

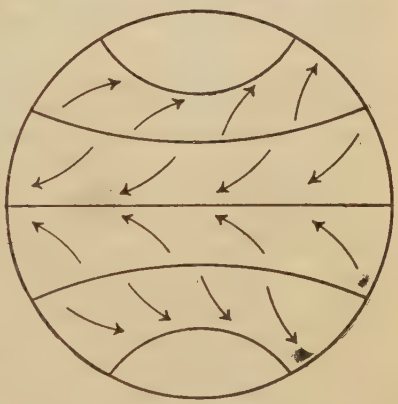

Fig. 62. Generalized diagram of wind directions at the bottom of the atmosphere.

The westerly winds of middle latitudes and the trades of low latitudes are the *prevailing winds* (*planetary winds*) at the bottom of the atmosphere.

Periodic Winds

When air is heated it expands, and a given volume of it becomes lighter. This results in movements of convection (Fig. 61). One of the movements involved in convection is horizontal, and horizontal movement of the air is wind. On a cold day in winter, with a brisk open fire, cold air may be felt moving along the floor toward the fire. Such movement is analogous to wind. *Unequal heating of the air is, therefore, a cause of air movements*, and since the air is being unequally heated all the time, unequal heating is a cause of constant atmospheric movements. Some of the movements are horizontal, and some vertical; some are in the lower part of the air, and some in the upper.

The unequal heating of the air is the immediate cause of

certain familiar winds and breezes, which blow at more or less regular periods and also interfere with the circulation indicated in Fig. 62.

Land- and sea-breezes. On a sunny summer day, the land becomes warmer than an adjacent lake or sea (p. 63). The result is that the air over the land is warmed and expanded more than that over the sea. Movement of the air follows. By day, especially after some hours of heating, the air moves in from the water to the land, at the bottom of the atmosphere. This is the *sea-breeze* or *lake-breeze*. At night the land cools more than the water, and the movements of air are reversed, giving the *land-breeze*, which blows from the land to the water, at the bottom of the atmosphere. The sea-breeze is strongest during the summer in warm regions. In many places it is felt inland 20 to 30 miles. It lowers the temperature over the land to which it blows, and makes the conditions of life on many tropical coasts much more agreeable than they would be otherwise. It is partly because of the cool, refreshing sea-breeze that many people go to the sea-shore during the hot months. When the sea, or lake, breeze has the same direction as the prevailing wind, it is so strong occasionally (as at Valparaiso, Chile) that business is stopped, and people forced to seek shelter. Along certain coasts, fishermen put to sea in the early morning with the land-breeze, and return toward night with the sea-breeze. The land-breeze may be very faint at night in spite of a brisk sea-breeze by day, because the land may not reach a temperature more than a few degrees below that of the water. The inequality of temperature is then not great enough to cause a distinct land-breeze. Fishermen and others who have stayed out after the sea-breeze stopped have been becalmed, and in some cases compelled to stay out all night.

The daily land- and sea-breezes are not usually felt far from shore, and do not extend to great heights. Breezes corresponding to land- and sea-breezes are often felt about large lakes. The sea-breeze is of consequence, not only by lowering the temperature of the land in hot weather, but by bringing pure air to the land. This is of much importance in influencing the development of shore resorts, and in making habitable many sections of tropical coasts. The effect of the daily sea-breeze on a tropical coast may be seen from the accompanying table of temperatures recorded at a station on the west coast of Africa, at different hours before (up to 12:30) and after (after 12:30) the breeze sprang up.

Hour	6 A. M.	8	10	12	12:30 P. M.	12:45	1	3
Wind Direction	E-N-E	E-N-E	N-E	N-E	N-E	N-W	N-W	N-W
Temperature	70°	81°	91°	100°	102°	82°	78°	75°
Relative Humidity	43%	24%	14%	4%	3%	45%	61%	65%

The effects of the sea-breeze are so beneficial in many places in the tropics that the natives of those regions call the sea-breeze the "doctor."

Monsoons. Some lands near the sea become so much heated in summer that the sea (from-sea) winds continue during the hot season, not merely through the hot part of the day, while the land (from-land) winds hold sway during the winter. This is the case, for example, in India. Such winds, which change their directions with the seasons, are *monsoon winds*.

India is in the latitude of the northern trades, where northeasterly winds should prevail, if the planetary system (Fig. 62) were

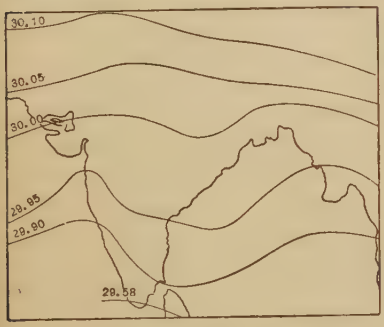

Fig. 63.

Fig. 64.

Fig. 63. The isobars of India for January. (Bartholomew.)
Fig. 64. The wind directions of India in winter. (Köppen.)

not interfered with. In Fig. 63 the gradient is from north to south, and the direction of the wind (Fig. 64) is in harmony with the planetary system (Fig. 62); but in Fig. 65 the isobaric gradient is to the northward, because the land is warmer than the sea, and the winds in the lower part of the air blow as shown in Fig. 66. That is, the planetary (northeast) wind is overcome during the hot season by the winds which result from the seasonal change of temperature. At the same season, the low pressure north of India, developed by the heat of summer, replaces the high pressure common in this latitude, and the prevailing trade-wind is displaced by seasonal winds. Figs.

67 and 68 show the isotherms for the same region at the corresponding seasons, and make clear the relation between pressure and temperature.

Fig. 65.

Fig. 66.

Fig. 65. The isobars of India for August. (Bartholomew.)
Fig. 66. The wind directions of India in summer. (Köppen.)

Monsoon winds influenced greatly the development and conduct of trade on the Indian Ocean. The systematic use of these winds caused a great expansion of the early trade between the Red Sea

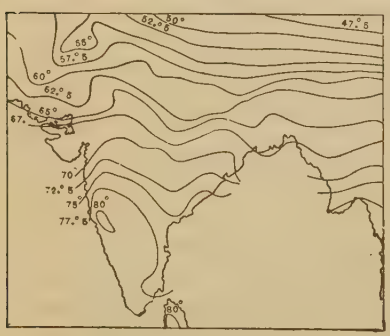

Fig. 67.

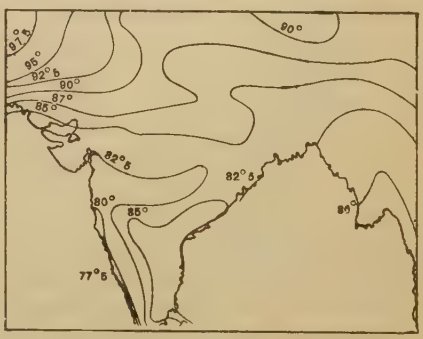

Fig. 68.

Fig. 67. Isotherms of India for January. (Buchan.)
Fig. 68. Isotherms of India for August. (Buchan.)

region and the East, and helped make Alexandria the commercial metropolis of the Roman Empire. Trading fleets left Berenice (western shore of the Red Sea) in July, when the southwest monsoon

would carry them to India, and started back about the first of January, so as to take advantage of the northeast winter monsoon. Later, vessels sailing from Europe timed their outward and homeward voyages so as to take similar advantage of these winds. Indeed until the time of steamships, all commerce on the Indian Ocean continued to be connected closely with the monsoons. Important early political expansions also followed in the track of the same winds. The monsoon winds of India have much to do with bringing moisture from the ocean, thus influencing the rainfall upon which the crops to feed 250,000,000 people depend.

Monsoon winds are not confined to India, though this name is not applied to all winds of this sort. In their summer seasons, all land areas are warmer than adjoining bodies of water; hence at any given altitude the pressure will decrease toward the land interior. This means an isobaric slope toward the land, as a result of which there will be a tendency for air to flow landward from the sea. In winter the reverse is the case, and the air movement will be from the land area toward the sea. If the air movement is with the prevailing wind, the latter is strengthened; if it is against the prevailing wind, it weakens the latter, or overcomes it altogether. Such *continental* and *oceanic* winds are developed well on the east coast of Asia. Spain, in the zone of westerly winds, affords another excellent example of seasonal winds. Winds due to the same cause are felt about the Great Lakes.

Mountain- and valley-breezes. Winds due to changes of temperature sometimes blow about mountains. *Mountain-breezes* blow from the mountains at night, and *valley-breezes* blow toward them on sunny days. Hence localities which are hot by day may be so situated as to receive cool mountain-breezes at night, making the nights comfortable. Various summer resorts benefit from such conditions.

Besides the planetary winds, the seasonal winds (monsoons), and minor periodic winds (such as land- and sea-breezes) whose times of blowing are more or less regular, there are numerous winds which blow at irregular times, and whose coming cannot be foretold long in advance. These irregular winds are the chief cause of the uncertain elements of the weather. Some of them are due to unequal temperatures, some to unequal amounts of atmospheric moisture, and some to other causes. These irregular winds will be considered in the next chapter.

Velocity and direction of the wind. Wind direction is shown by a weather vane, which points toward the quarter *from which* the wind is blowing. Wind directions are shown on maps by means of arrows which point toward the quarter *to which* the wind is blowing. Wind velocities are measured by an *anemometer* — constructed on the same principle as the cyclometer on a bicycle — which shows the number of miles travelled in any interval of time. Wind velocities, however, are expressed usually in miles per hour; thus trade-winds are said to blow from 10 to 30 miles an hour. The United States Weather Bureau also uses descriptive terms (as light, fresh, brisk) for a regular scale of wind velocities.

A wind velocity of 60 miles per hour causes a wind pressure of nearly 10 pounds per square foot at sea-level, while at 90 miles an hour this pressure is doubled. Hence the destructive violence of winds of high velocity.

In general, the average velocity of winds is greatest in latitude 50° or thereabouts. The average velocity for the United States has been estimated at about 9.5 miles per hour, and for Europe 10.3. The velocity of winds is, in general, greater over the sea than over the land, largely because moving air is checked on land by friction with the uneven surface. It is greater in the upper air than in the lower, for the same reason. But the *force* of the wind at high altitudes is less than for the same velocities at sea-level, owing to the lesser density above. The average velocity is greater in winter than in summer, because the barometric gradient between the equator and the pole of the hemisphere having winter is greater than that of the other hemisphere.

The greatest velocities, rising to 100 or more miles per hour, always are associated with irregular winds, and it is to them that the most destructive wind action is due. Some irregular winds blow from directions very different from those of prevailing winds. In middle latitudes, the sudden changes of temperature always are due to winds of this class.

Winds and Rainfall

Importance of rainfall. Perhaps the most useful service of the wind is in the distribution of the moisture evaporated from ocean and land. Rainfall is of great importance to all plants and animals which live on the land. Few plants live in desert regions, and few animals live where plant life is scanty. Human industries, too, are much affected by rainfall, for no arid region supports a dense popula-

tion, and no agricultural country, aside from small irrigated areas, can be prosperous, if the rainfall is unreliable.

Less than one-thirtieth of the people of the United States live in the third of the country where the rainfall is less than 20 inches per year. Soil is not productive unless adequately watered, even though it be rich in the elements necessary for plant food. Rainfall also plays a large part in determining the character of many soils. Thus in some dry regions, the sandiness of the soil is due to the lack of moisture, without which that sort of mineral decay necessary to form clay cannot take place. Some desert soils are alkaline, because the soluble compounds of sodium and potassium (known as *alkalies*) have not been removed by water. Most plants will not grow in alkaline soils. The absence of moisture retards the development of humus, an important part of good soils.

Twenty inches of rain per year usually is considered to be the minimum for general agricultural purposes, but something depends on (1) temperature, (2) the soil, and very much on (3) the time of year when the rain falls, and (4) the rate of evaporation, as determined by temperature, soil, and wind. The warmer and drier the climate, the more the water needed for crops. The total amount necessary is less if it falls when the growing crops need it most. That the total amount of rain for a year may not be the most important thing may be shown by comparing two places with about the same annual amount, but differently distributed. For general agricultural purposes, without irrigation, Concordia is far ahead of Red Bluff.

						3.9 in. (6 months)						
	Annual	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Red Bluff, Cal..... (Winter rain.)	25.7	4.7	3.5	3.2	2.1	1.3	0.5	0.0	0.0	0.6	1.5	3.0	5.3
						20.2 in. (6 months)							
Concordia, Kas.. . . . (Summer rain.)	26.8	0.7	0.8	1.5	2.3	4.7	4.3	3.7	2.9	2.4	2.2	0.8	0.5

It is best for agriculture to have the rain come in the season when temperatures are most favorable for plant growth. Hence in middle latitudes, summer rain is of more value than winter rain. Rain or snow falling at times when plants are not growing is, however, not useless to them, for some of it remains underground, and is taken up by their roots at a later time.

Irrigated land does not depend directly on rain and snow, but the water used in irrigation is derived from the atmosphere, though in many cases the water falls far from the place where it is used. Thus in the Indus Valley, millions of people are supported by irrigation from streams which get their water largely from melting snows in

the Himalaya Mountains. A very porous soil loses its moisture more quickly than a more compact one, and so needs more rain for crops.

Rain and snow are important not only as a source of water for soil, but as a source of supply for streams and wells. A mantle of snow also prevents great changes in the temperature of the soil beneath, and in this way protects many plants. So important is this effect that in some regions a heavy snow generally means good yields of fall-sown crops the next year. Snow hampers some kinds of transportation and favors others. In lumbering, for example, snow makes the hauling of logs easier. Rapidly melting snow and heavy rainfall on frozen ground cause destructive floods. Heavy rain in a city is beneficial in flushing and cleaning the streets and in washing out of the air a large part of its impurities. On the other hand, it may flood cellars and basements, doing great damage. Rain and snow both hinder the circulation of dust and bacteria, thus further contributing to health.

The distribution of rainfall is influenced largely by winds, which carry moisture from the places where it is evaporated to the places where it is precipitated (Fig. 69). Winds help to determine where rain falls, how much falls, and at what times of the year. The rate of rainfall also is important. More moisture may enter the soil from a light, gentle rain, than from a heavy downpour. Washing of the soil is also greater when torrential rains fall. We conclude that a given amount of water falling as light, gentle rains is better than a larger amount falling rapidly, for of the latter a large part runs off immediately (Why?).

The precipitation of any given region depends largely on (1) what winds affect it, (2) the topography of the surface over which the winds blow before reaching it, and (3) the topographic situation and relations of the place itself.

Relation of rainfall to general winds. In the trade-wind zones, the winds blow from higher to lower latitudes, and therefore, on the average, from cooler to warmer places. As the air is warmed, it can hold more moisture. So long as the trades blow over the sea or low land, they take moisture, but do not drop what they have. It follows that on the sea, and on comparatively low lands, like the Sahara, the trade-winds are "dry." A part of Australia lying in the belt of the southeast trades is also dry.

If, however, the air of the trades is forced up over mountains, it is cooled, and some of its moisture may be condensed and precipitated. *The windward sides of high mountains in the trade-wind zone have heavy rainfall.* An illustration is afforded by the east side of the

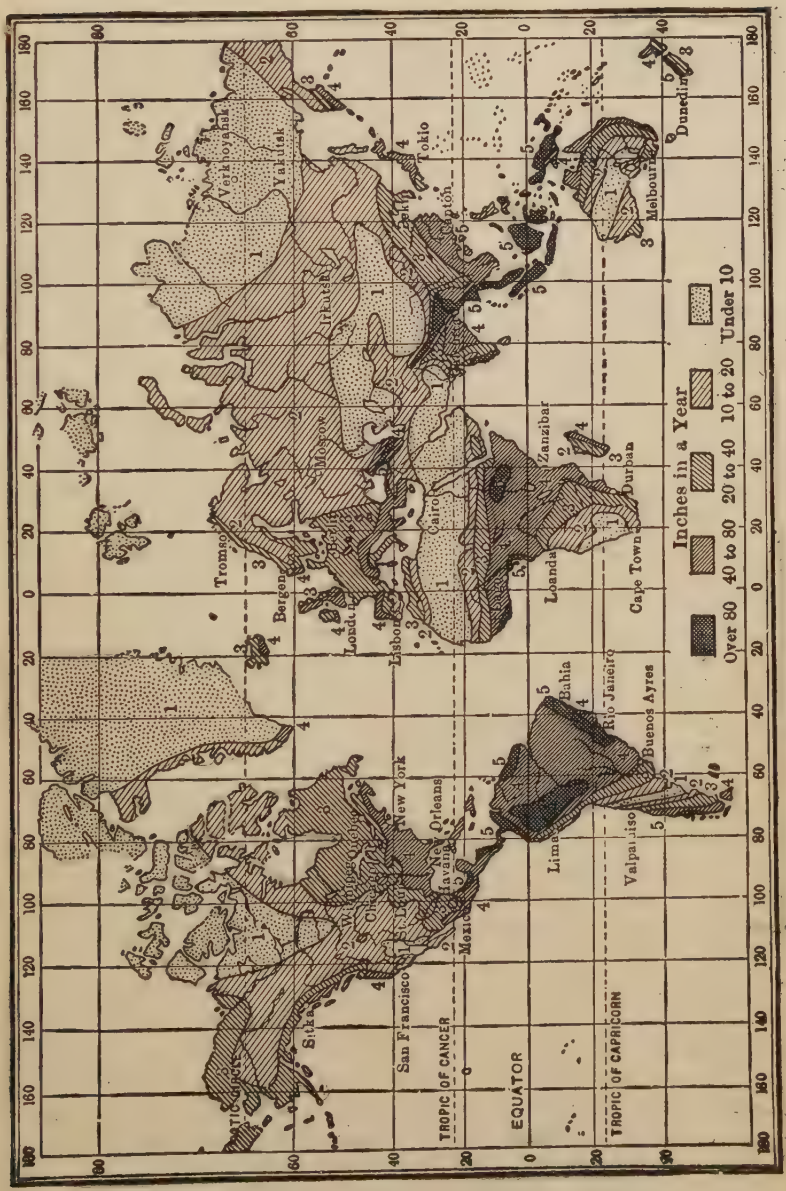

Fig. 69. Map showing mean annual precipitation for the world.

Andes Mountains in the trade-wind zone (Fig. 69). Another example is furnished by the volcanic cones of the Hawaiian Islands. The trade-winds yield little rain to their lower slopes, but, forced up over the mountains, they yield abundant moisture at higher levels. The levels of heavy rainfall may be readily seen, because of a change in the vegetation. Even in the middle of the Sahara and of Australia, some rainfall is caused by high hills and mountains which stand in the path of the trade-winds.

After the air of the trades passes over a mountain range, it descends, and is warmed both by contact with the warm surface and by compression. It therefore takes up moisture. *The leeward sides of mountains in the trade-wind zones are therefore regions of little precipitation.* The west slope of the Andes Mountains in the zone of the trades furnishes an example in the coastal desert of Peru.

Rainfall in the zones of the prevailing westerlies. The principles which apply to the rainfall in the trade-wind zones apply also in the zones of the westerly winds. These winds are, on the whole, blowing from lower to higher latitudes, and so are being cooled gradually. They may, therefore, yield some moisture, even at sea-level or on low land, and especially on land in the winter season. The heat of the land in summer often prevents condensation and precipitation of the moisture in the westerly winds, until the air has moved far to poleward. But when such winds cross mountains, they yield moisture to their windward slopes and summits, and become dry on the leeward slopes (Fig. 69).

From these principles we may understand the rainfall of the United States, so far as it depends on planetary winds. The prevailing winds, for most of the country, are from the southwest. Coming to the land from the Pacific Ocean, these winds find the land cooler than the ocean in winter, and warmer in summer. In winter they yield moisture, even at low levels. This gives the low lands of California their wet season. As the winds blow across the mountains back from the coast, they yield more moisture, so that all the area west of the top of the first high ranges, the Sierras at the south and the Cascades at the north, is supplied with rain and snow in the winter season. As the winds blow beyond the Sierra Nevada and Cascade mountains, the air descends and becomes warmer, and therefore dry. East of these mountains lie the arid and semi-arid lands of the Great Basin with its Great Salt Lake, and of eastern Oregon and Washington.

The effect of altitude on rainfall may be illustrated by the rainfall at different altitudes in crossing the Sierra Nevada range from the west.

	Altitude, feet	Rainfall, inches
Sacramento, W. side of range	75	20
Colfax, W. side of range	2,400	45
Cisco, W. side of range	5,940	50
Summit	7,000	46
Carson City, Nev., E. side of range	4,674	10.8

In general, precipitation increases up to an altitude of 4,000–6,000 feet; above 6,000 feet it decreases generally. One important effect of increased precipitation at high altitudes is the great winter snowfall, amounting to 20 or 30 feet in some places. This interferes seriously with the business of railroads which cross such regions. The relation of precipitation to altitude is shown in the distribution of vegetation on mountains. Thus on the San Francisco Mountains, in Arizona, desert vegetation prevails up to an altitude of 5,900 feet, while from 6,800 up to 11,000 feet, various types of trees are found in abundance.

When the westerly winds from the Pacific reach the higher parts of the Rocky Mountains, which are higher in many places than the mountains farther west, they again yield some moisture. But farther east, all the way to the Atlantic, these winds are dry, for they cross no more high mountains, and they do not generally go far enough north to reach a temperature as low as that of the mountains they have passed. For some distance east of the mountains the rainfall is slight; but east of central Kansas and Nebraska the lands are well supplied with moisture. It is therefore clear that something besides the westerly winds brings rainfall to this region. This agent is the irregular *cyclonic wind*, to be studied in the next chapter.

The winds which blow from the Pacific to the continent in summer have a different effect upon rainfall. At this time of year, they find a temperature on the coastal low lands higher than their own. They are therefore "dry" in this region, and give to much of California its dry season. Blowing inland, these winds reach mountains so high that the temperature is low enough to cause condensation and precipitation, even while the low lands to the west are dry. In Washington, the mountains near the coast are high enough to cause precipitation even in summer. In Alaska, where some of the mountains always are covered with snow, precipitation is heavy in summer, and at high altitudes much of it falls as snow.

Monsoon winds may yield much moisture. In general, they blow toward warmer regions, and so should be dry; but they may be forced up over high mountains, and precipitation follows. They are assisted also by convection currents over the warm land, in producing rainfall of the thunder shower type. The heaviest rainfall on record, on the southern slopes of the Himalayas, is due to monsoon winds. As in the case of the planetary winds, it is the windward sides of the mountains which receive the heavy precipitation from the monsoons. It is clear, therefore, that *the windward sides of high mountains are places of heavy rainfall and snowfall.*

Land- and sea-breezes rarely yield much rain, though they may give rise to fogs when they blow from warmer water to cooler land, or when, at the opposite season, they blow from warmer land to cooler water. Some valley-breezes give rise to heavy showers.

Variation in rainfall. Some places which were once moist are now dry, as shown, for example, by petrified forests in the desert of southwestern United States. It is believed that a similar change in the past has made large areas of central Asia, formerly inhabited, too dry to support more than the scantiest population. In most places, the rainfall of corresponding months or seasons is rarely the same from year to year. These temporary variations are important factors (1) in floods, which in some cases cause great damage to property and heavy loss of life (p. 366), and (2) in droughts, which frequently result in even greater loss through damage to crops, and in some countries, as India and China, through deaths from famine. The United States, fortunately, rarely suffers from widespread failure of rain. Australia, on the other hand, has more than once been crippled by long-continued, severe droughts. In the United States, it has been shown that, with other conditions equal, the yield of corn depends directly on the amount of rain falling in June and July. When the amount is small, the crop is short. Other crops show similar close relation to rainfall. The importance of good crops to the prosperity of the country indicates that relative reliability of rainfall is a great national asset.

Questions

1. What effect do high altitudes have on the power of a steam engine?
2. What weather conditions might indicate whether the pressure is high or low?
3. Explain fully the effects on men (1) of a brisk wind, and (2) of calm air, in *summer*, in Louisiana. The same for *winter*.
4. Why are the westerly and the trade-winds appropriately called *planetary winds?*
5. Explain the significance of the data given in the table on page 115.
6. On which side of Lake Michigan is the lake-breeze stronger in summer? Why?
7. At what time of year would seasonal winds from Lake Michigan be most felt in Chicago?
8. How much force is exerted on the side of a house 60 feet long by 25 feet high, when a wind is blowing 90 miles an hour?
9. How do seasonal (ocean-continent) winds affect the temperature of the east coast of North America in summer? In winter? How do they affect the west coast at the two seasons?
10. Is the *force* of a wind which has a velocity of 20 miles an hour likely to be greater in summer or in winter at the same place? Why?
11. In general, are winds stronger in California in winter or summer? Why?
12. Why are the most desirable residential quarters of many manufacturing centers in the United States located to the west and northwest of the city?
13. Suggest reasons why many coastal districts have more rain in winter than in summer; why the reverse is true for most continental interiors.
14. Name the kinds of vegetation which you would expect to find at an altitude of 7,000 feet in the middle of the Sahara.
15. In what portions of the world would power from the wind be most reliable? In what portions of the land areas? Why? Where is it most likely to be utilized by man?

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CHAPTER VIII

STORMS AND WEATHER FORECASTING

Weather Maps

Irregular winds have been mentioned (pp. 117, 123) as important factors in the distribution of rainfall and in changes of temperature. Such winds are associated with local and temporary conditions of pressure. Temperature, wind, rainfall (or snowfall), and cloudiness are the important elements in the weather of any place for any given time. As these elements are combined in different ways from day to day, the weather varies. Weather changes are important in so many ways that it is desirable, if possible, to know beforehand what changes are likely to occur. Thus winds of great velocity are dangerous to shipping at sea, and vessels, if warned of their approach, may remain in port. A freezing temperature in spring or autumn may cause losses amounting to hundreds of thousands, or even millions of dollars; but if sufficient warning is given, it is possible in some cases to protect perishable crops. In these ways and many more, weather changes and weather forecasting affect everyday life.

Since weather changes are associated directly with irregular winds, and these in turn depend on pressure, it is evident that weather forecasting must depend largely on a study of pressure conditions. Changes of pressure from day to day have much more to do with weather changes than anything else has.

Isobaric lines (p. 104) and isothermal lines may be put on the same map, which may show also where the sun is shining, where it is cloudy, where it is raining, snowing, etc. Such a map is a *weather map*, and may be made for any region, to show the weather at any given time. Thus Fig. 70 is a weather map of the United States for January 9, 1911. Like all weather maps, it shows (1) isobars (full lines); (2) the direction of the winds (shown by arrows); (3) the degree of cloudiness; (4) areas of precipitation; and (5) isotherms (broken lines).

Weather maps for the United States are made by the Weather

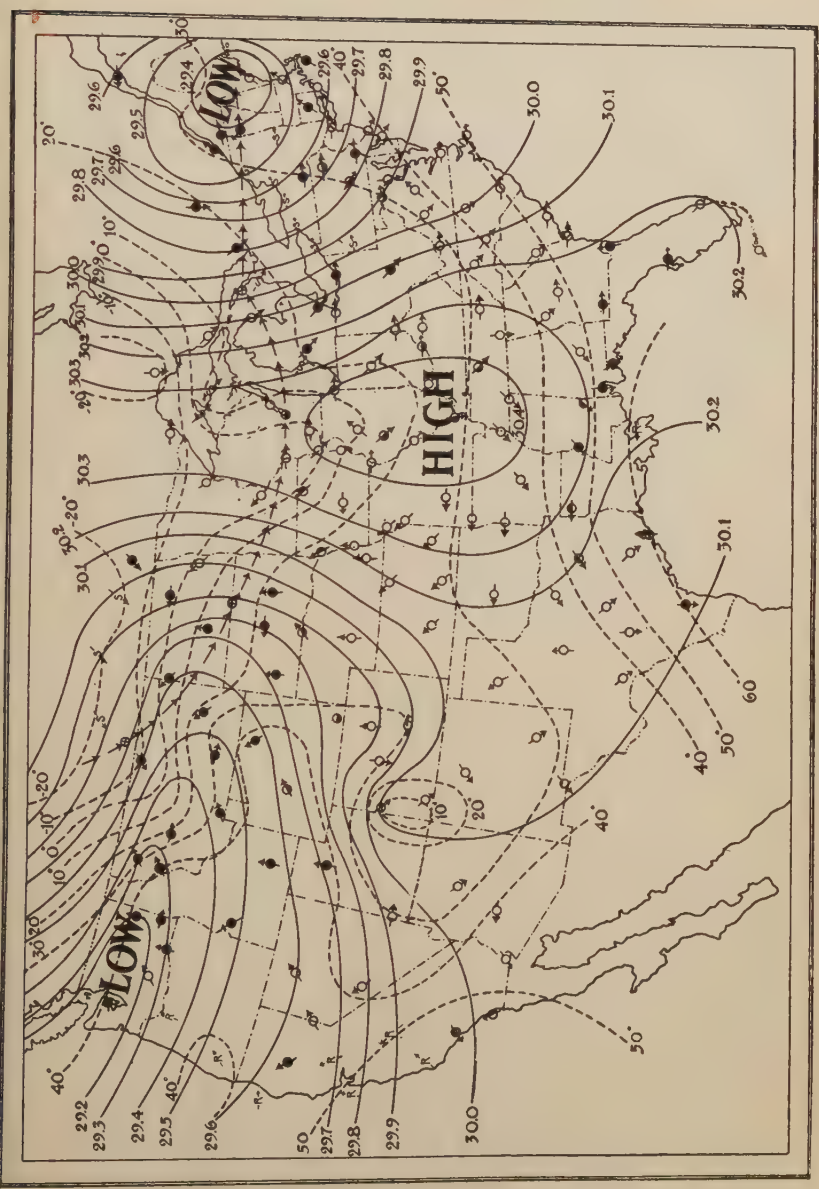


Fig. 70. Weather map for United States, January 9, 1911.

Bureau, a branch of the Federal Department of Agriculture. They are prepared in the chief cities, where telegrams are received twice daily from numerous stations in different parts of the country. Each telegram tells the pressure, the temperature, the direction and velocity of the wind, the cloudiness, and the rainfall at the station whence the telegram is sent. These stations are established and maintained by the Government.

Explanation of the Map

(1) **Isobars.** The isobars of the map (Fig. 70) show a range of pressure from 30.4 inches in the area centering in the Mississippi Valley, to 29.4 in Maine, and 29.2 in Washington. The pressure is more than 30 inches in the central part of the country, and less than 30 inches on both the Atlantic and Pacific coasts.

The isobar of 30.4 in the central part of the United States is a closed line. The center of this high-pressure area is marked "high" (p. 102). West and east of the high the pressure decreases steadily toward the coasts, where there are centers of low pressure, marked "low" (p. 102). The minimum pressure in the low near the Pacific coast (29.2) is less than that in the low over Maine (29.4). Atmospheric pressures generally are unequal in different parts of the country. Hence most weather maps show both lows and highs, or at least one of each.

(2) **Winds.** Wherever barometric pressures are unequal, isobaric surfaces are uneven and winds are the result. The arrows on a weather map show the direction of the winds. On January 9, 1911 (Fig. 70), winds were blowing away from the high and toward the lows. The movements of air out from an area of high pressure constitute an *anticyclone*, and the movements in toward an area of low pressure constitute a *cyclone*. A cyclone is one type of a *storm*. The winds in a cyclone are not always strong — rarely strong enough to be destructive. The violent wind-storms, popularly called cyclones, should be called *tornadoes*.

Winds do not blow straight out from the anticyclonic centers, nor straight in toward the cyclonic centers. They may *start* straight out from the center of each high, but in the northern hemisphere they are turned (deflected) toward the right (right-hand half of Fig. 71, N), as most of the arrows about the anticyclone (Fig. 70) show. Similarly, the winds which blow toward the cyclonic centers do not blow straight toward them, but are deflected a little to the right in the northern hemisphere, as most of the arrows about the lows (Fig. 70) show. In

the southern hemisphere, the winds are turned to the left instead of to the right (Fig. 71, S).

The weather map tells nothing directly about actual wind velocities. On government maps, this information appears in a table of data printed on the margin. But the strength of the winds at various points may be inferred from the map. The distance from the center of the low in the east (Fig. 70) to Lake Michigan is about 800 miles. The difference in pressure is about .9 inch. This would cause a wind of about 30 miles an hour — a high wind — between these points. In general, the gradient is high and the winds strong where isobars are crowded.

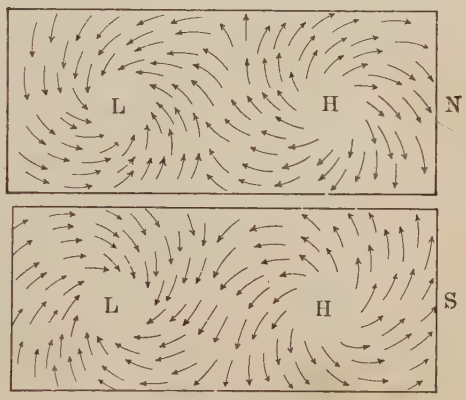


Fig. 71. Diagrams to show the circulation of air about a low, L, and a high, H, in the northern hemisphere (N) and the southern hemisphere (S).

As air moves in toward the center of a cyclone, it also moves spirally up. This upward movement has an important effect on precipitation (p. 123). The upward and outward course of the air in a cyclone is shown in Fig. 72, which represents a vertical section of a cyclone. The outflow above is chiefly to the eastward, the direction toward which the prevailing winds of middle latitudes blow.

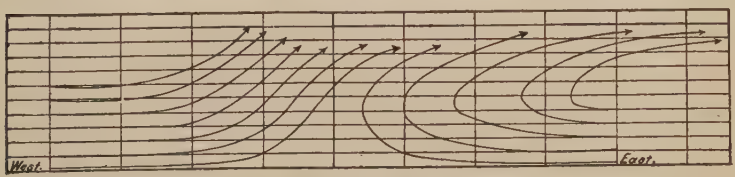


Fig. 72. Diagram illustrating the general movement of air currents in a cyclone of middle latitudes. The upper air moves mainly toward the east, in the direction of the prevailing winds.

(3) **Cloudiness and precipitation.** An open circle on the shaft of an arrow (Fig. 70) indicates clear skies, a half-blackened circle (as

in Wyoming) shows that the sky is partly cloudy, while a black circle (as in Montana) indicates general cloudiness. Cloudiness is estimated by the weather observers. If less than three-tenths of the sky is covered by clouds, the observer records clear; if from three-tenths to seven-tenths, the record is partly cloudy; if over seven-tenths, cloudy. An *R* on the shaft of an arrow (as in California) indicates rain, and an *S* in the circle on the shaft of the arrow (as in New York) shows that snow is falling. The map tells nothing about actual amounts of precipitation, but they are given in the printed table with the other data for each station.

(4) **Temperature.** As indicated above, the broken lines of a weather map are isotherms.

The isotherms of Fig. 70 show two distinct features: (1) they have little relation to parallels, and (2) the isotherms bend northward where the pressure is low, and southward where the pressure is high. This last feature is shown in most of the weather maps which follow; but on many of them the isotherms follow the parallels more closely than in Fig. 70.

Cyclones and Anticyclones

Characteristics of highs and lows. The highs and lows are sometimes much more pronounced than those shown in Fig. 70. In Fig. 73 the low is more pronounced, the pressure ranging from 29 at the center, to 30.1 in the East, and to 30.5 in the West. So great a range of pressure within the United States is not common. The isobars are closer together in this figure than in Fig. 70, and therefore indicate stronger winds. Cloudy skies prevail in the southeastern part of the cyclone.

Highs as well as lows may have great area. Fig. 74 shows a high, or anticyclone, more than 2,000 miles across, with a great range of pressure. The isotherms of this chart, like those of the preceding, stand in very definite relations to the isobars. Denver, in the anticyclone (temperature $-10°$), is about 30° colder than the southern part of Maine, which is 3° farther north, but on the western border of a cyclone.

Near centers of low pressure, precipitation takes place in many cases, while around centers of high pressure there is, as a rule, an absence of precipitation. The chief reason for rainfall or snowfall about a low is that the inflowing air produces an upward spiral current, and the rising air expands and is cooled (p. 92), and so gives up some of its moisture. In the northern hemisphere, southerly

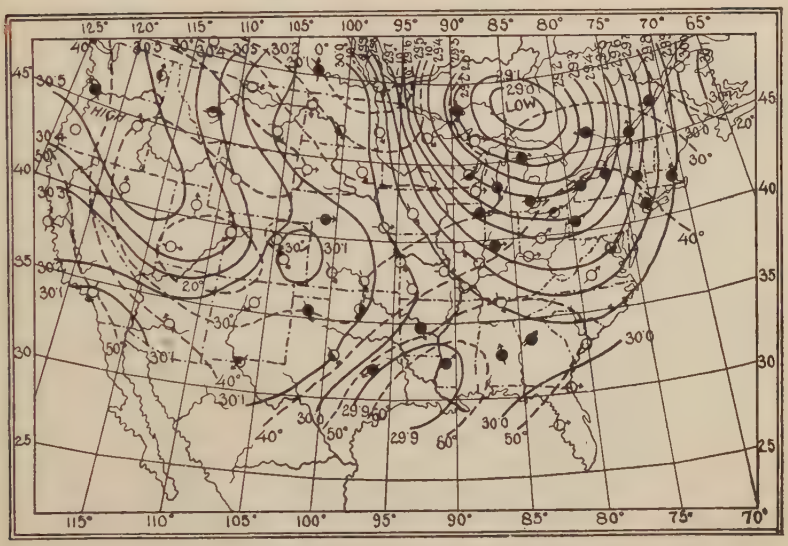


Fig. 73. Weather map for January 16, 1901, showing a very pronounced low.

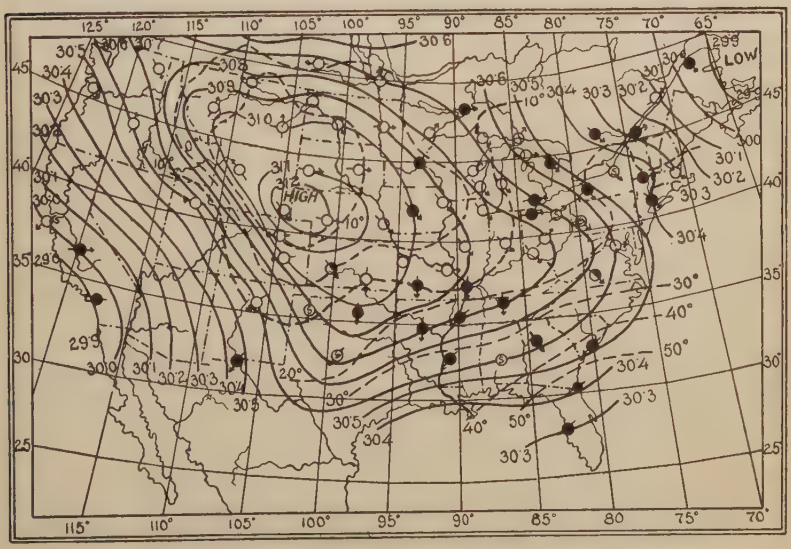


Fig. 74. Weather map for December 9, 1898, showing a high of great size.

winds to the southeast of storm centers are, in general, blowing from warmer to cooler places, and this may result in precipitation. The prevailing winds which influence the direction of outflow in the upper part of a cyclone (Fig. 72) tend to carry the rainfall to the east of its center.

This circulation of winds around cyclonic areas is the real factor in drawing moist air northward from the Gulf of Mexico, and in giving abundant rainfall east of the Mississippi River.

In an anticyclone there is a descending spiral movement of air. The descending air comes from an altitude where the air is colder than that at the bottom of the atmosphere, and hence brings a low temperature. Winds from anticyclones generally bring clear weather, but cold air moving down and out from an anticyclone may mingle with warm air about it, so as to cause some of the moisture of the latter to condense, giving rise to clouds, or even to precipitation.

Movements of cyclones and anticyclones. Highs and lows do not remain in the same place from day to day. This is shown by Figs. 75-78, which are the weather maps of four successive days. In these figures precipitation is shown by shading.

In Fig. 75 there is (1) a low along the Atlantic coast; (2) a high central over Iowa; (3) a feeble low north of Montana; and (4) a high in Oregon. The map of the succeeding day (Fig. 76) shows (1) that the low of the St. Lawrence Gulf has disappeared (moved to the east); (2) that the high of the Interior has moved to West Virginia; (3) that the low which was north of Montana has moved to Dakota; while (4) the high of the Oregon coast remains about where it was. The map of the next day (Fig. 77) shows (1) that the high of the Virginias has moved on, but not so far as on the preceding day; (2) that the low which was over North Dakota is now north of Lake Superior; (3) that the high of Oregon has moved east to Idaho and Montana; and (4) that a weak low has developed in Oklahoma. The map of the 27th (Fig. 78) shows (1) that the high which was over the Virginias has disappeared to the east; (2) that the low which was north of Lake Superior is now north of Lake Ontario; (3) that the high of Montana has moved southeast to Kansas; (4) that the weak low which was in Oklahoma has disappeared; and (5) that another feeble low has appeared in southern California.

The rate of progress of a storm is not the same as the velocity of its winds. The velocity of the wind depends on the isobaric gradients. A weak cyclone, that is, a cyclone in which differences of pressure are

Fig. 75. Weather map for September 24, 1903. The shading on this and succeeding maps indicates areas of precipitation during the preceding 24 hours.

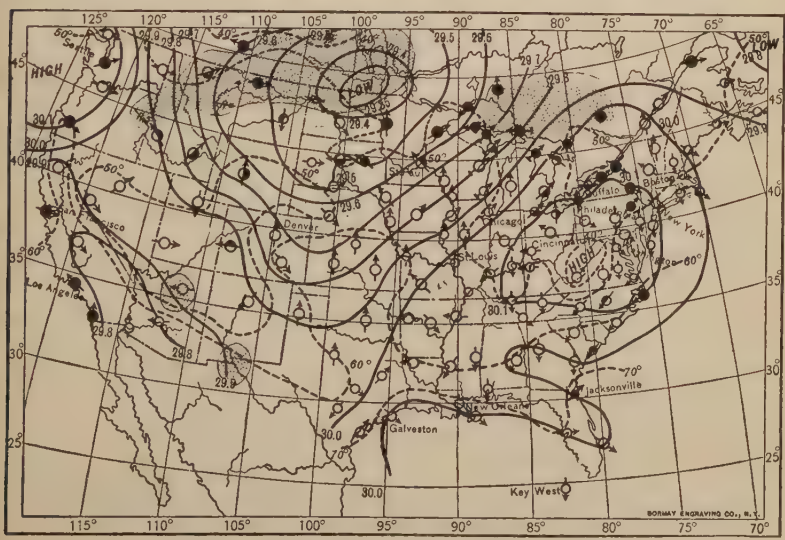


Fig. 76. Weather map for September 25, 1903.

Fig. 77. Weather map for September 26, 1903.

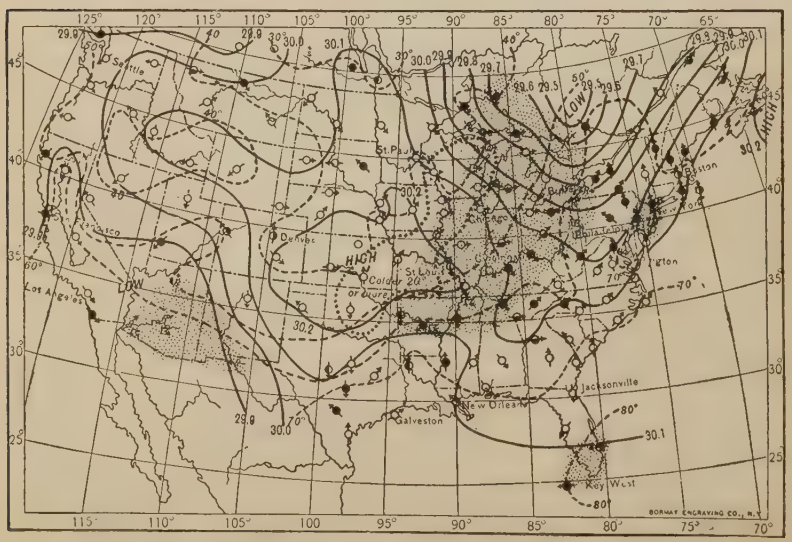


Fig. 78. Weather map for September 27, 1903.

not great, gives rise to weak winds, even though the center of the storm moves rapidly. A strong cyclone, that is, one in which the differences of pressure are great, gives rise to strong winds, even though the cyclone itself may move forward slowly.

The rate at which cyclones move varies with the season, the average being about 37 miles per hour in winter and 22 in summer. Storms may move at twice these rates, however, or at less than half their usual speed.

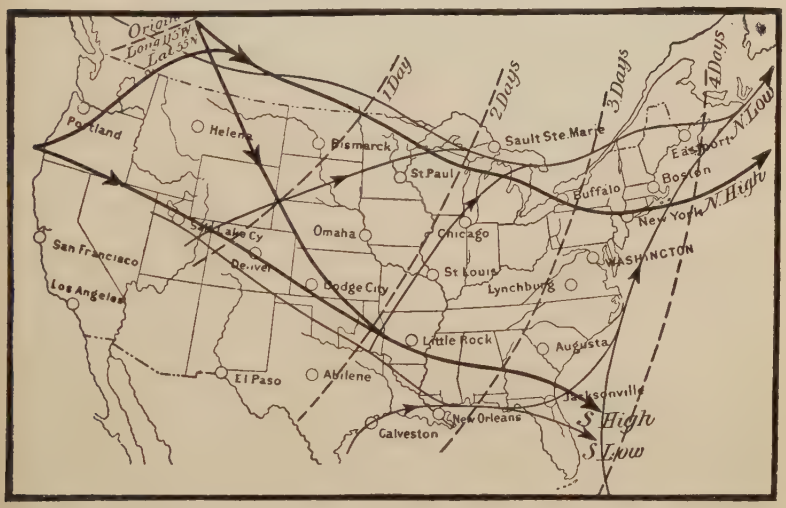


Fig. 79. Chart showing the mean tracks of cyclones (light lines), anticyclones (heavy lines), and average daily movement (broken lines).

The course of a cyclone may be shown on a single map, as in Fig. 70. The row of arrows shows that the low of Maine has moved from western Canada.

The mean tracks of cyclones and anticyclones for the United States are shown in Fig. 79. The broken lines on this map, marked 1 day, 2 days, 3 days, and 4 days, show the average daily progress of storms which come from the northwest.

Some anticyclones enter the United States from the Pacific, while others start north and northwest of Montana, or, at any rate, are first reported from there. Cyclones originate in various places. More of them originate near the places where anticyclones start than in

other places; but many appear first in Colorado, the Great Basin, Texas, and elsewhere.

The passage of a cyclone or anticyclone involves a change in the direction of the wind, and usually also changes of temperature, humidity, and cloudiness. Thus in Fig. 76 the wind at St. Paul is southeasterly, though this city is in the zone of westerly winds. The next day, after the storm center has moved forward to a position northeast of St. Paul (Fig. 77), the wind is northwesterly. An east wind is often the first sign of an approaching cyclone; and since many cyclones bring rain, an east wind is generally taken as a sign of approaching rain throughout much of the United States.

Cyclones are, on the whole, more frequent and better developed in winter than in summer. They do not affect the air to great heights. Even when the great whirl or eddy is 2,000 miles across, as is sometimes the case, its height (depth) is rarely more than 4 or 5 miles. The origin of the cyclones and anticyclones of middle latitudes is not well understood.

Winds and temperatures incidental to cyclones and anticyclones. During the passage of a cyclone, the air to the southeast of the storm center is drawn from warmer (lower) to cooler (higher) latitudes. In midsummer this often gives rise to a *hot wave*, though not all hot waves are associated closely with cyclones. Similar winds are known as the *sirocco* in the western Mediterranean region. In eastern United States, numerous sunstrokes and deaths from heat prostration accompany some hot waves in their progress across the country. In Mediterranean countries, the sirocco often combines high temperature and extreme humidity. Such conditions are very trying, as indicated by a Spanish proverb: "Ask no favor while the *solano* (sirocco) blows." The famous *brickfielder* of Australia, and the *zonda* of Argentina are winds of this same origin, and similar winds have other names elsewhere.

Air to the northwest of a cyclone moves from cooler (higher) to warmer (lower) latitudes. In winter, this may give rise to *cold waves*. These cold winds are known as *northers* in the southern part of the United States, and sometimes as *blizzards* in the northern part, though this name usually implies heavy snowfall and high wind, as well as low temperature. Fig. 80 shows the weather map for January 3, 1896. The isotherms bend southward about the high, so that central Texas and Montreal have about the same temperature. On the following day (Fig. 81) a freezing temperature has

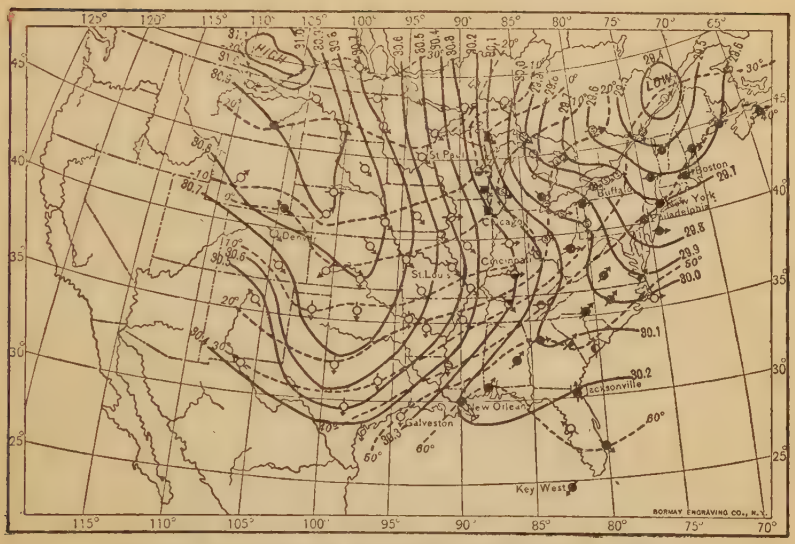


Fig. 80. Map showing the cold wave of January 3, 1896.

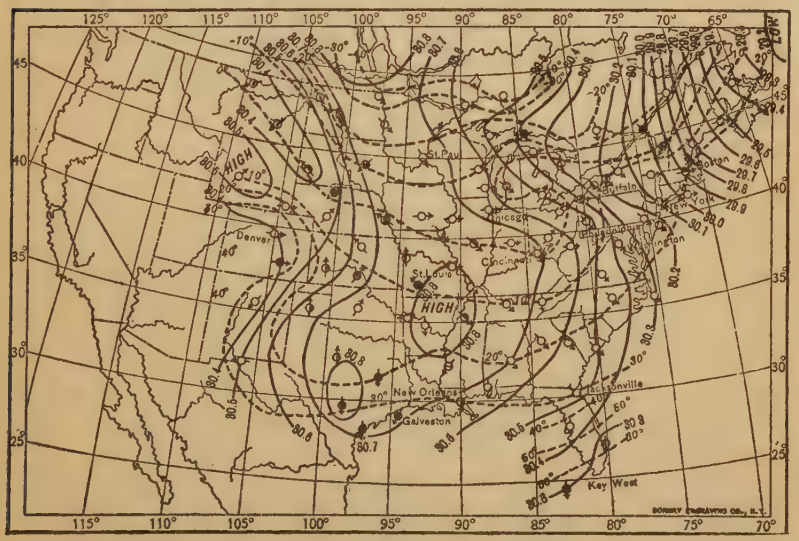


Fig. 81. Map for January 4, 1896, showing the progress of the cold wave of Fig. 80

been carried down to the orange groves of northern Florida. Among the other names by which similar cold winds are known are *mistral* in southern France, *bora* along the Adriatic, *southerly burster* in Australia, and *pampero* in Argentina.

When warm, moist air is forced up over mountains, it precipitates some of its moisture (p. 123). The precipitation sets free heat, so that the rising air is cooled much less than it would be otherwise. Beyond the crest of the mountains it descends, and is warmed in the process. It is warmed much more (often twice as much) in the descent than it was cooled in the ascent. It may, therefore, descend as a hot wind. Such winds are known as *foehn* winds in Switzerland, and as *chinook* winds in the United States, especially just east of the Rocky Mountains.

These winds may be beneficial or harmful. Thus the chinook winds temper the rigorous winters of certain parts of the northwestern states and the Canadian provinces east of the mountains. They frequently evaporate a foot or more of snow in a few hours. For this reason they are sometimes called "snow-eaters." These winds make winter grazing possible over large areas which otherwise would be covered heavily with snow. In the province of Alberta the chinook has been declared to be "the grand characteristic of the climate as a whole, that on which the weather hinges." These winds sometimes develop with great suddenness. At Fort Assiniboine, Montana, on January 19, 1892, the temperature rose 43° F. (from −5.5° to 37.5°), in fifteen minutes, under the influence of the chinook wind. In other cases the temperature has been known to rise 80° in six or eight hours.

The chinook winds of summer are sometimes so hot and drying as to wither vegetation, and occasionally to destroy crops. The Swiss foehn is so dry that general conflagrations among the wooden cottages are feared greatly, and in some villages all domestic fires are extinguished while the foehn blows.

Tropical cyclones. Cyclones sometimes start in tropical regions, and follow courses very different from those of the cyclones of middle latitudes. The cyclones of this class which reach North America usually originate in the West Indies, and are most common in late summer and early autumn. They follow a northwesterly course until the latitude of Florida is reached. Here they commonly turn to the northward, and later to the northeastward, following the Atlantic coast. The heavy line of Fig. 82 shows the average path of tropical cyclones for the months of August, September, and October, for the years 1878 to 1900.

Tropical cyclones (*hurricanes*) are stronger than those of intermediate latitudes; that is, the gradient and the winds are higher, the velocity of the wind in many cases exceeding 100 miles an hour. Many of these cyclones do great damage along the coast, both to shipping

and to low lands near the water. The great storm at Galveston, in September, 1900, resulted in a loss of 6,000 lives, and damage to property estimated at more than $30,000,000. Fig. 83 shows (1) the course of the storm before it reached Galveston and after leaving it, and (2) the rate of its progress. The strength of the storm was exceptional, and its course unusual, as will be seen by comparing Fig. 83 with Fig. 82. Much of the destruction was due to water driven by the high winds over the low island on which Galveston

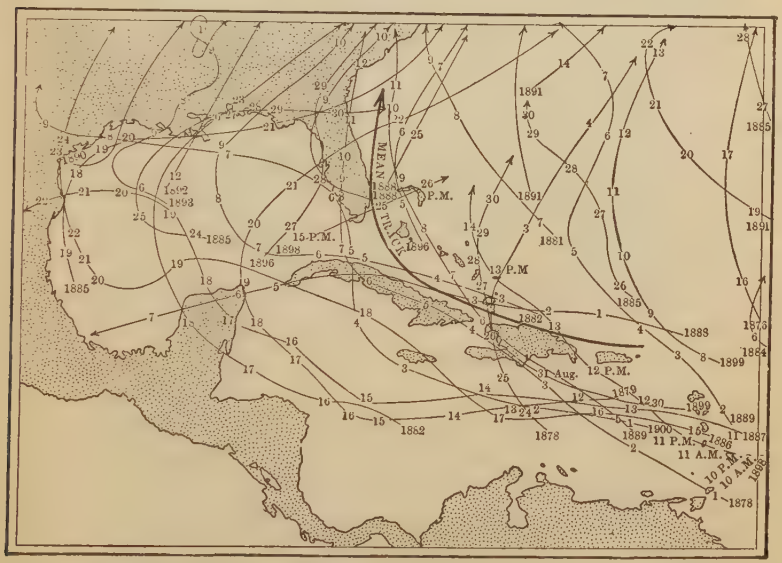
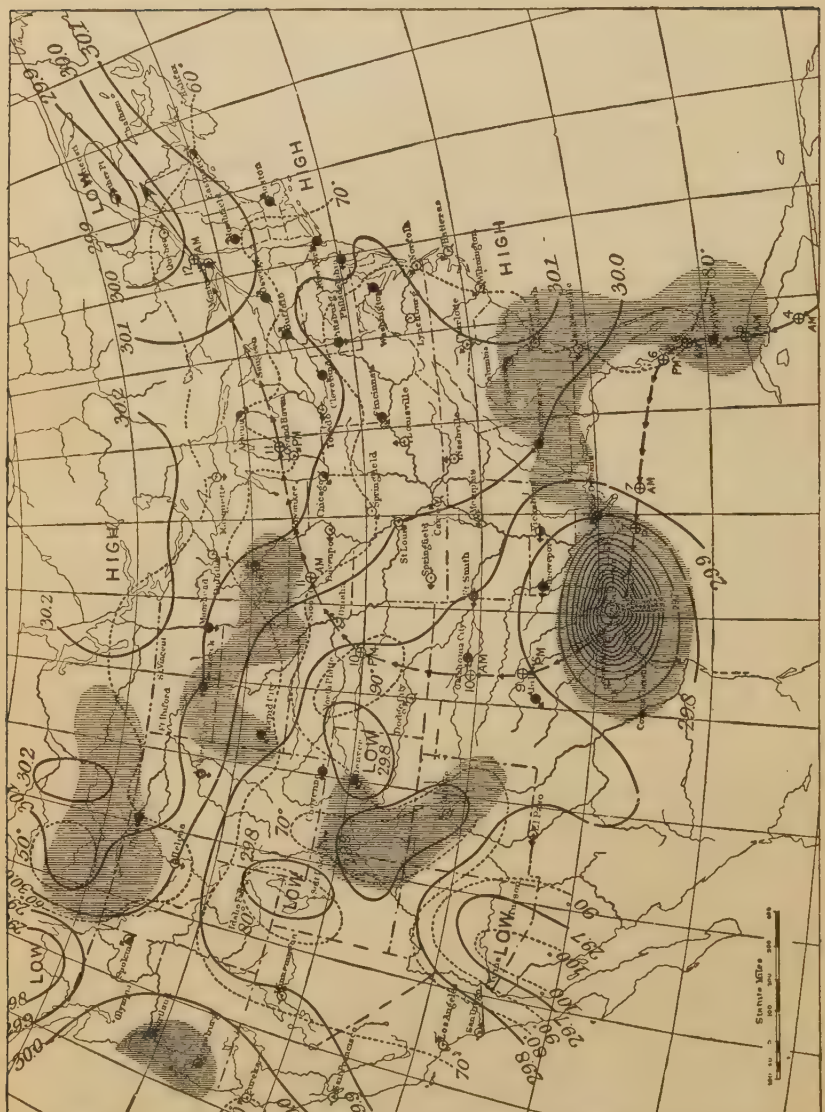


Fig. 82. Course of West Indian storms for August-October, 1878–1900. The heavy line indicates the mean track.

stands. An expensive sea-wall (Figs. 84 and 85) has since been built, and the level of the city raised, to prevent the recurrence of such a disaster.

In September, 1906, a West Indian hurricane swept the Gulf coast of Florida and Alabama, and then passed inland, with damage to shipping and crops estimated at 15 to 25 millions of dollars. These tropical storms are so violent that any vessel, except the staunchest steamship, once within the storm's grasp, rarely escapes. For this reason there has been much careful study of these storms. Elaborate sailing directions, giving instructions how to escape from them, are now an essential part of the equipment of every vessel frequenting the oceans where tropical cyclones occur.


HIGH
HIGH
HIGH
LOW
LOW
LOW
LOW
LOW
30.2
30.0
29.8
29.6
29.8
29.7
29.8
29.8
29.8
29.8
70°
70°
70°

In the Atlantic, tropical cyclones occur north of the equator, though not south of it; in the Pacific, they occur both north and south. They occur in the later part of the hot season, and consequently are

Fig. 84. Portion of the sea-wall built to protect Galveston.

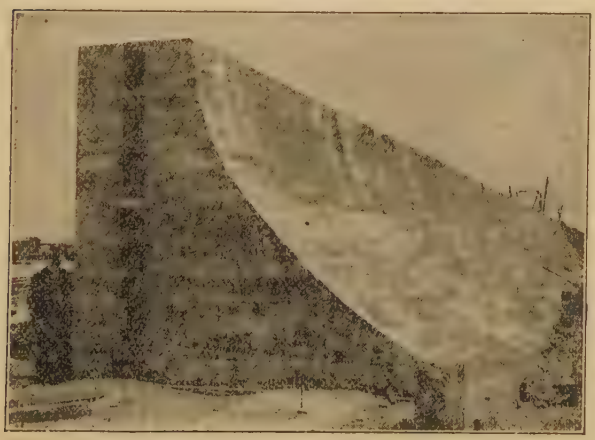


Fig. 85. A cross-section of the Galveston sea-wall, showing plan of construction and relative dimensions. The right-hand side faces the sea.

believed to be strong convection (p. 61) currents. The tropical cyclones of the North Pacific, called *typhoons*, start somewhere east of the Philippines, and sweep the coast of China (Fig. 86). Tropical cyclones are much less frequent than cyclones of middle latitudes; otherwise, the portions of the tropics affected would be almost uninhabitable. Islands which lie near cyclone tracks suffer severely. Porto Rico, for example, has been devastated five times within the last century (1825, 1837, 1867, 1899, and 1910). The storm of 1899 was probably the worst, and the entire island was crippled. Coffee, sugar-cane, and tobacco crops were destroyed almost completely, more than 3,300 lives were lost, and the property damage was estimated to be not less than $35,000,000. During this storm 23 inches of rain fell in 24 hours.

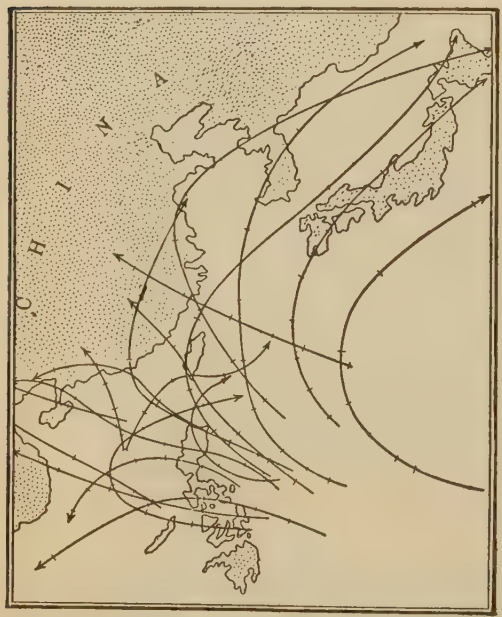


Fig. 86. Typhoon tracks. (Herbertson.)

Weather Forecasting

Weather predictions. Weather predictions are based on the facts shown on weather maps. As a rule, official predictions are made only for the 36 or 48 hours immediately following the hour when the map is made. Take, for example, the map of the 25th of September, 1903 (Fig. 76). Rain accompanies the cyclone which is central over Dakota. Since this storm has, for the last 24 hours, been moving a little south of east at the rate of about 40 miles an hour, it is fair to presume that it will move in this same general direction at a similar

rate for the next 24 hours. If, in this time, it advances to the Lake Superior region, it probably will bring with it weather similar to that which it is now giving to the region where it occurs. Hence, on the 25th, the prediction might be made that rain is to be expected in about 24 hours in the region about the head of Lake Superior.

On the 26th the prediction might be made that the low which is central north of Lake Superior (Fig. 77) will move on to the Gulf of St. Lawrence by the succeeding day, and that increasing cloudiness and rain will accompany it. Rain for the region about Lake Huron and the area east of it may, therefore, be predicted for the 27th. The chart for that day (Fig. 78) shows that the area of precipitation extends far to the south. The preceding map had shown some cloudiness in this region, but had afforded no warrant for the prediction of such an area of precipitation as appears on the map of the 27th.

Temperature changes as well as changes in cloudiness and precipitation may be predicted. Thus in Fig. 75 the isotherm of 50° bends southward notably in the high, central over Iowa. As the high moves east, it will probably carry the low temperature with it. Hence it is safe to predict that the temperature will fall in the area into which the anticyclone is to move. The map of the succeeding day (Fig. 76) shows that the temperature of western Virginia has fallen from about 60° to about 40° along the path of the high, while areas much farther north are warmer.

Fig. 76 also shows that North Dakota and Alberta have a temperature of 50°, that is, a temperature 10° warmer than that of western Virginia. It will be noted, too, that the relatively high temperature of Dakota, Montana, and Alberta goes with a low. As the cyclone moves eastward, the temperature along its path will probably rise. This is shown by the map of the next day (Fig. 77), which shows a temperature of about 50° north of Lake Superior. The same map shows how the isotherm of 40° bends to the southward in front of the high which is central over western Montana. As the high of Montana moves eastward, it will be likely to carry a low temperature with it. From this map, therefore, it may be predicted that the temperature in Nebraska, Kansas, Iowa, and Missouri will fall.

The time when the rain which a storm may bring to any given place will fall is calculated from the rate at which the storm is moving. In the same way, the prediction of the time of arrival of a cold wave which an anticyclone may bring is based on the rate of progress of the anticyclone. This rate is known in advance by

telegraphic reports. Predictions concerning the weather may be made more readily for the central and eastern parts of the United States than for the western part, for the storms have been under observation longer before they reach the central and eastern states.

Long-range weather predictions. Attempts often are made to predict weather changes and conditions for a whole year, or for the different seasons. Without exception, these so-called "predictions," based on the color of goose-bones, the thickness of fur of animals, the state of the weather on certain "sign days," and so on, are mere guesses. Like all guesses, they sometimes hit, but more often miss. For all practical purposes, they are worthless.

There is no doubt that forecasts of the weather for longer intervals would be immensely valuable if they could be made with accuracy. Recently the Weather Bureau has attempted forecasts for a period of a week in advance, and in some cases has met with a fair degree of success. These long-range forecasts depend on a study of pressure conditions over most of North America, and as far as possible over the adjacent oceans. As more comes to be known concerning the origin of cyclones and anticyclones, their relation to pressure conditions and to the upper air, and as larger areas are brought under observation, it seems likely that fairly good forecasts can be made for periods of several days.

Failure of weather predictions. Weather predictions, even for short intervals, often fail. The reasons are many, among them the following:

(1) Cyclones and anticyclones sometimes depart widely from the courses they commonly take. Thus a storm may be in line for St. Paul, to which it is expected to bring rain and a rising temperature; but instead of keeping its course, it may turn off to the northward, and the rain which was predicted for that city falls farther north.

(2) Storms change their rate of advance, and so arrive earlier or later than predicted. The high of Oregon (Fig. 75) did not advance for a day (Fig. 76), and so failed to bring the expected changes to the area east of it.

(3) Again, storms sometimes appear and disappear without warning. Fig. 77 shows a low over Oklahoma, of which there had been no indication on the 25th. Fig. 78 shows that this low has disappeared.

(4) A storm sometimes changes its character, becoming weaker or stronger, etc. Figs. 87 and 88 afford an illustration. Nothing

in the map of the 20th would warrant the prediction of the conditions of weather shown on the map of the 21st.

(5) Sometimes predictions are based on imperfect data. On some weather maps the letter *M* appears in various places. This means that reports from the stations where the *M* appears are missing. If many reports are missing, the map is imperfect, but the forecaster must use such data as he has, as well as he may, and issue a map.

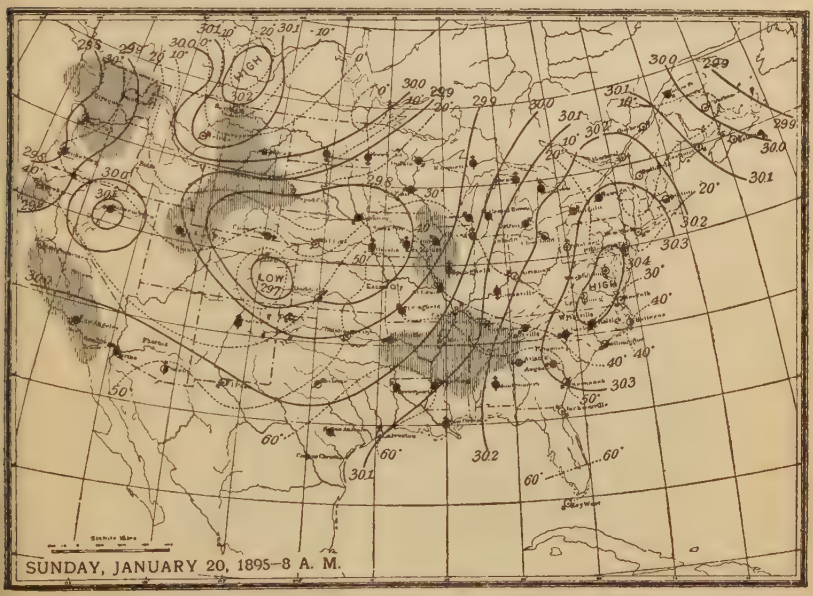


Fig. 87. Weather map for January 20, 1895.

(6) In some situations storms are subject to many freaks. This is the case, for example, at Chicago, where Lake Michigan modifies temperature and air currents.

Forecasters, like other men, make mistakes, but when they have to work with so many uncertain elements, it is not strange that their predictions sometimes are wrong, and one mistake is likely to be remembered longer than many correct forecasts.

Value of weather forecasts. In spite of all mistakes, the warnings of storms, floods, cold waves, etc., sent out by the Weather Bureau, have been of great benefit. The value of this service is not

always duly appreciated, and much less is heard of it than would have been heard of the losses which would have resulted if warnings had not been given. Unfortunately, it is not always possible to devise protection against the evils of which the Weather Bureau gives warning. It has been estimated that property valued at $15,000,000 was saved in 1897 by warnings of impending floods. In 1903–4 the estimated saving was $1,000,000.

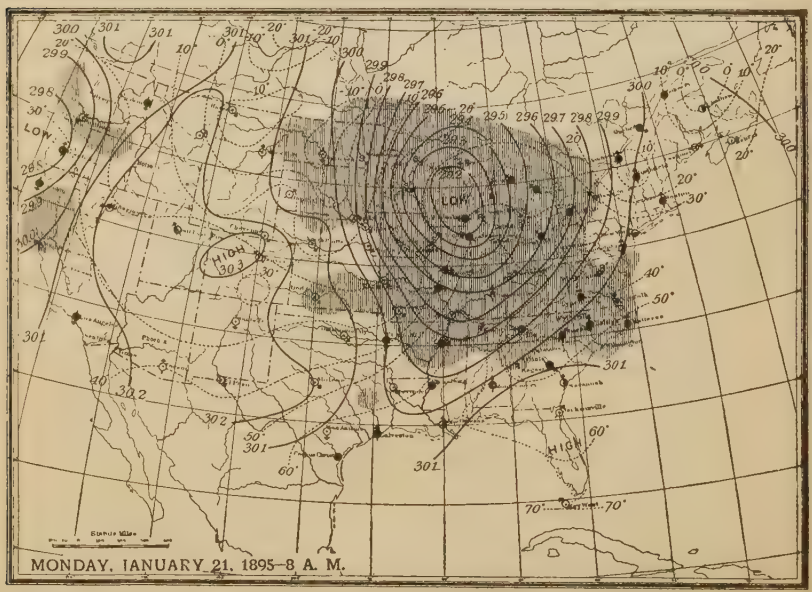


Fig. 88. Weather map for January 21, 1895, showing the storm of the preceding day greatly increased in intensity.

Shipping interests are served by warnings of storms. Thus, in September, 1903, vessels valued at $585,000 were held in ports temporarily, along the coast of Florida, by storm warnings. The loss of the Boston steamship *City of Portland*, with all on board, in the great storm of November 28, 1898, was due to a failure to heed storm warnings which kept all other craft in port.

Agricultural interests also are served by warnings of storms and of "cold waves," and especially of frosts. Warnings led to the protection of $1,000,000 worth of fruit about Jacksonville, Florida, in 1901, with an estimated saving of half this amount. Other warnings of cold in 1901 were estimated to have been the means of saving more then $3,000,000 worth of property. Fruit and truck farming are the phases of agricultural work served most effectively in this way. Shipments

of perishable products, like most fruits, may be damaged badly if freezing temperatures are encountered unexpectedly in transit. Merchants handling such products are saved much trouble and inconvenience by information from the Weather Bureau concerning the temperatures for which their shipments must be prepared.

The annual saving of property in these various ways exceeds, several times over, the total cost of the Weather Bureau.

Local Storms

Thunder-storms. Thunder-storms are frequent in the United States. They are most common in warm regions, and in warm seasons. Further, they are most common on days which are unusually warm, and during the warmer parts of these days; but there are occasional thunder-storms in the winter, and there are thunder-storms at night.

The first indication of a thunder-storm is usually a large cumulo-nimbus cloud (Fig. 89), which, in the zone of the westerly winds,

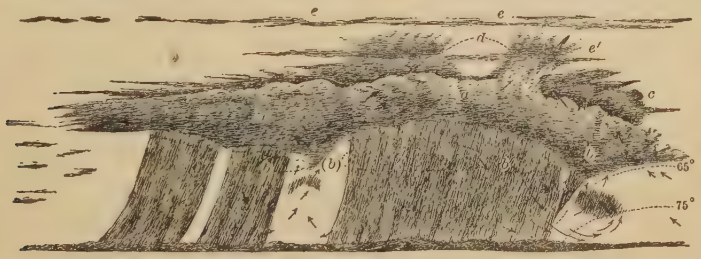


Fig. 89. Vertical section of a thunder-storm which is moving toward the right. (Köppen.)

generally appears in the west. It moves eastward, and as it reaches the place of the observer, there is usually a smart breeze, or *thunder-squall*, rushing out before it. Shortly after the squall the rain begins to fall. The rainfall may be heavy, and the drops large, but the downpour does not usually last more than an hour, and in many cases much less. A second thunder-storm sometimes follows close upon the first, thus prolonging the period of rainfall. When a thunder-storm has moved on to the east, the air is, in many cases, notably cooler and fresher, and the barometer distinctly higher. But when the sun reappears quickly, rapid evaporation may raise the humidity to a point which makes the air extremely oppressive. Hence a

thunder-storm cannot always be counted on to relieve the heat of a damp, midsummer day.

Lightning is due to the discharge of electricity from one part of a cloud to another, or from one cloud to another, or from the cloud to the ground. When lightning discharges come toward the ground, they seek exposed objects in some cases and cause loss of property, chiefly through fire, and occasional loss of life. The total of both, however, for a year, is much smaller than that from fires due to other causes. Buildings may be protected from lightning by carefully erected lightning rods; but rods carelessly constructed or adjusted are worse than none.

The flash of lightning is followed by thunder, the noise being due to vibrations in the air caused by the electrical discharge. Thunder has been compared to the noise which follows the explosion of a rocket or the cracking of a whip.

In middle latitudes, most thunder-storms occur during the passage of cyclones, though they do not accompany all cyclones. They are more common on the south sides of cyclones than elsewhere, and many of them occur at a considerable distance from the center of the main storm. In middle latitudes, most thunder-storms move from west to east, while in the zone of trade-winds they move from east to west. In both cases they move with the prevailing winds.

Much of the precipitation from summer cyclones is connected with thunder-storms. Hence localities having most of their rain during the warm season depend largely on thunder-storms for moisture. This condition is characteristic of much of central and eastern United States. Not infrequently violent thunder-storms give precipitation in the form of *hail*. The exact conditions producing hail are not known, but in regions subject to frequent hailstorms, as some parts of Mediterranean Europe, the annual damage is heavy.

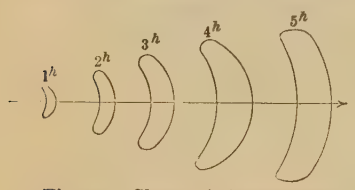


Fig. 90. Shape of thunder-storm in ground plan, illustrating its growth and change as it progresses. (Waldo.)

The forward movement of thunder-storms is commonly 20 to 50 miles an hour. Many of them spread and become weaker as they move forward (Fig. 90). Most of them disappear before they have traveled far. The period of a thunder-storm is usually much shorter than that of the cyclone which it accompanies.

It sometimes happens that lightning at a great distance lights the clouds over a region where the electric discharge itself cannot be seen. This lighting of the clouds is often called *heat lightning*, because it is more commonly seen in hot weather than at other times. The *rainbows* which accompany or follow many thunder-storms are due to the effects of the drops of water in the atmosphere as the sun's rays pass through them.

Whirlwinds. Ascending whirls of air are seen frequently on hot days. They are most distinct in dusty regions, for there the

dust which is swept up makes the whirl conspicuous. From a given point in the Mojave Desert, in California, as many as eight or ten of these whirls, some of them rather large, have been seen at one time on a hot summer day. Several are occasionally in sight at once from a train as it passes through this region in summer. The whirlwinds probably are caused by the excessive heating of the air at some point, and this excessive heating gives rise to a sharp convection current. The whirl moves on for a time with the prevailing wind, but soon dies out. The dreaded *simoons* of the Arabian and African deserts are strongly developed, dust-laden whirlwinds.

In humid regions, whirlwinds do not usually appear to extend up to any considerable height; but in desert regions they may reach heights of 1,000 feet or more, as shown by the columns of dust. The rise is sometimes so great that the air is expanded and cooled enough to cause condensation of even the small amount of moisture contained in the desert air. Smart showers may then occur. Showers of this sort are likely to be of short duration, but the rainfall may be very heavy. If exceptionally heavy, such rains are known as *cloudbursts*. In such a storm, in the summer of 1898, rain enough fell in a few minutes, in the vicinity of Bagdad, in the Mojave Desert of California, to occasion serious washouts along the railroad for miles. A cloudburst at Clifton, S. C., June 6, 1903, caused the loss of more than 50 lives, and property damage to the estimated extent of $3,500,000. In desert regions, the water which starts to fall from the rising and expanding air is sometimes evaporated before it reaches the ground. Such "suspended" showers may be seen often in Arizona in August.

Tornadoes. When a convection current is very strong, and has a very small diameter, the whirl becomes so intense in some cases as to cause great destruction. A whirling storm of this sort is a *tornado*. Tornadoes, like thunder-storms and whirlwinds, are phenomena of hot weather. They occur in the United States in the hot days of spring and early summer, appearing earlier in the south, and later in the north. This relation of tornadoes to the warm season is indicated by the fact that of 600 recorded tornadoes, nearly two-thirds occurred in the four months, April to July, and less than one-eighth in the four months, November to February. They are rather less abundant in the later part of the summer than in the earlier part. They are more likely to occur in a cyclone than in an anticyclone. Tornadoes are associated in most cases with hot days, and with the warmest part of the day.

The atmospheric pressure in the center of the tornado is usually much lower than in the center of a cyclone. In a very strong tornado, the pressure at the center may be a fourth less than that of its surroundings. This is one reason why the tornado is so destructive. During its passage, the pressure may be reduced from the normal amount, 14.7 lbs. per square inch, to three-fourths of this, or to 11 lbs. per square inch. If such a tornado passes over a closed building in which the air pressure is 2,117 lbs. per square foot, the pressure on the outside becomes 1,584 lbs. The walls are therefore pushed out with a force of 533 lbs. per square foot, and unless they are very strong, they will fall, as if the building had exploded. In some cases only the weaker parts, such as windows, yield.

Not only is the pressure at the center of the tornado very low, but the area of this low pressure is very small. While a cyclone may be 1,000 miles or more across, few tornadoes are more than a mile across. Most of them do not exceed 1,000 feet in diameter at the surface of the land, and many are only a few yards wide.

Fig. 91. Funnel-shaped cloud of a tornado, Solomon, Kas. (U. S. Weather Bureau.)

The result is that the pressure gradient in a tornado is very much higher than in a cyclone, and the winds are violent. Their velocities, estimated by the size and weight of the objects moved, have been thought to reach 400 or 500 miles per hour. With this velocity, or even a velocity which is much less, destruction is great. Trees are overturned, buildings unroofed or blown down, and bridges hurled from their foundations.

A tornado is often seen first as a funnel-shaped cloud (Fig. 91), the point of which may be far above the ground. As the funnel moves forward, its lower end may rise or fall. The cloud is due chiefly to the condensation of moisture in the sharp convection current, and the funnel shape is due to the expanding and spreading of the air as it rises.

The tornado is, of all storms, the most destructive, but, in most cases, it has a very narrow track, and does not work destruction for a very great distance. After a short course of 15 to 30 miles, most tornadoes die out, or rise above the land.

One of the most destructive, though not one of the most violent, tornadoes of recent times was that at St. Louis, May 27, 1896. It accompanied a thunderstorm in the southeastern part of a cyclone, central some distance northwest of the city. The wind velocity indicated by the instruments at the Weather Bureau office was 128 miles per hour at the time the anemometer was blown away. One of the extraordinary features of this storm was the fact that its base was about 30 feet above the surface. Trees were twisted off at this level, and the principal destruction of houses was above the first floor.

As in other tornadoes, the wind played many curious freaks. Single stones and bricks were picked out of walls, while the walls remained standing. In one case a pair of horses attached to a loaded wagon were blown away, though the wagon was not overturned. The destruction of property in and about St. Louis was estimated at about $13,000,000.

A more violent tornado was that at Louisville on the 27th of March, 1890, just before nine o'clock in the evening. Many weak buildings were wrecked, 76 persons were killed and about 200 injured in Louisville alone, and the loss of property was estimated at about $2,500,000.

The number of tornadoes is probably not increasing even in the section of the central and lower Mississippi Valley where they occur most frequently. It is likely, however, that the increasing number of towns and villages in this district may mean greater loss from these storms. No device is likely to be of any use in preventing or breaking up tornadoes. Neither is tornado prediction practicable at present, on account of the impossibility of determining just where the narrow track will be, and the undesirability of sending out broadcast warnings. Hence, in spite of the fact that the weather map may show conditions favorable for tornadoes, they are not mentioned in the forecasts.

In recent years, insurance of property against loss by tornado has become quite common in the states most affected, until at present the value of the property so insured is estimated at considerably over $500,000,000. It has been estimated that any given area in the tornado region the size of an average farm (say 160 acres) stands 1 chance in about 1600 of being hit once in 100 years. Hence if tornado risks are distributed carefully, even such a disaster as at St. Louis would not wreck the insuring companies.

Waterspouts. Waterspouts are tornadoes at sea. When the base of the upward spiral movement is at the surface of the water,

sea-water may be drawn up to some extent by the ascending current. But the larger part of the water in a waterspout is probably formed by the condensation of the water vapor in the air, and not by the uplift of water from the sea. Waterspouts, however, are much less common than tornadoes on land, since water areas, as a rule, do not favor the development of the strong convectional currents essential for these storms.

Questions

1. From Fig. 70, p. 127, suggest reasons (1) for cloudiness along the Gulf coast and in Montana, (2) for the absence of cloudiness in Kansas, and (3) why the isotherms bend southward in Illinois.

2. Explain the apparent contradiction in the fact that northeast winds, in most areas of the United States, are part of a storm coming from the west.

3. Show by a series of diagrams, in their proper order, the weather changes which would take place at a given station on three successive days under the following conditions: (1) On the first day the storm center (low) is approaching from the southwest; (2) on the second day at noon the center is 200 miles away, directly to the south; (3) on the third day it has moved on in the normal direction, and at the normal rate. Diameter of the low, 1,000 miles.

Make similar diagrams for a storm following a track 200 miles to the north of the station.

4. At many places, cloudiness on the southwestern horizon, especially in the evening, is regarded as a sign of a storm the following day, and the appearance of clear sky on the northwestern horizon is regarded as evidence of the end of a storm. Give reasons for these beliefs.

5. Formulate rules for forecasting temperature when the weather map shows isotherms running (1) east and west, and far apart; (2) north and south, and close together.

6. What basis in fact have the following weather proverbs: (1) "Too cold to snow." (2) " A white frost is a sign of a fair day to follow." (3) "Rainbow in the morning, sailors take warning; rainbow at night, the sailors delight." (4) "If the wind sets with the sun, there will be a frost." (5) "A mild, sunny day in winter is a weather breeder" (meaning that a storm will follow within 24–36 hours).

7. Suggest other weather proverbs which you have heard, and show whether or not they have any basis of truth.

8. Why are large dealers in grains, cotton, and tobacco interested in the daily weather map?

9. Draw diagram (using isobars) of a West Indian hurricane off the coast of Florida, with a sailing vessel in the vicinity of the storm area. Trace the probable course of the ship if it sails with the wind. Remembering that the vessel can sail in any direction except against the wind, indicate the proper course for the ship to take to escape the storm when it is (1) to the east of the probable storm track; (2) west of the track; (3) directly in the path of the storm.

10. Where do the storms originate (Fig. 79) which give rain to the agricultural regions south and west of Chicago?

11. Compare the effect of winter cyclones (see Fig. 79) on the weather of (1) New England, and (2) the Dakotas.

12. Suggest some of the changes in the climate of the United States which would result (1) if the Rocky Mountains ran east and west, along the entire length of the Canadian boundary; (2) if the area of the Gulf of Mexico were land.

13. What would be the effect of continued high pressure over the upper Mississippi Valley in summer? In winter?

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CHAPTER IX

TROPICAL CLIMATE

Distribution

Extent of tropical regions. The tropical zone, as usually defined, is limited by the Tropic of Cancer on the north, and the Tropic of Capricorn on the south. Other definitions of this zone have been suggested, as (1) the zone between the poleward limits of the trade-winds in the northern and southern hemispheres, and (2) the zone where the palm-tree grows naturally, the palm being taken as the type species of tropical vegetation (Fig. 92). While each of these definitions of the tropical zone has merit, the definition by parallels is used here, as being most precise and simple. The tropical zone covers about two-fifths the area of the earth. Within it, land and water are distributed very unequally.

Land and water areas—Western Hemisphere. The tropical part of North America includes most of Mexico, all of Central America and the islands to the east, or about one-seventh of the area of the continent. This area supports about one-sixth the people of the continent. If the tropical zone were defined by winds or by the distribution of palms, as suggested above, its area and population would be greater. North of the equator, the Gulf of Mexico and the Caribbean Sea make a big expanse of water almost in the heart of the tropics, and these bodies of water are of great importance to the climate of the eastern half of the United States (p. 132), as well as to that of the lands to the south.

South America contains the largest tropical land area in the Western Hemisphere, nearly three-fourths of it lying between the Caribbean Sea and the Tropic of Capricorn. The tropical part of this continent contains fully three-fourths of its population. Brazil, the largest country of South America, is almost wholly tropical (Fig. 92). Chile and Argentina are the only important countries of this continent lying mainly outside this zone.

Land and water areas—Eastern Hemisphere. Of the northern continents of the Eastern Hemisphere, only the southern penin-

sulas of Asia and the islands associated with them are south of the Tropic of Cancer (Fig. 92). The tropical parts of Asia make only about one-fifth of its area, but they support fully half its population.

Africa occupies, in the eastern world, the same relative position that South America does in the western. Fully three-fourths of its area and two-thirds of its population are between the tropics of Cancer and Capricorn. Even those parts of Africa which lie outside the tropics have climatic conditions not greatly different from those of the tropical parts of the continent.

About half of Australia and one-fourth of its population are within the tropics, and the climate of the remaining half is not very different from that of the tropical zone.

Summary. About one-third of all the land — in round numbers, 17,000,000 square miles — lies within the tropics. This third of the land supports about one-third the population of the earth, — in round numbers, 500,000,000 people. Much tropical land is desert, and much is covered with dense forests (Fig. 96). These parts are but sparsely populated, but the fertile and cultivated portions of this zone support dense populations. In Java, for example, 30,000,000 people live in an area two-thirds the size of Pennsylvania.

The area of ocean within the tropics is about 70,000,000 square miles. The large proportion of water in this zone is of special significance, for it gives much of the land marine climatic conditions.

Fig. 92. Map of the tropical regions, showing land and water areas. Poleward limit of distribution of palm trees ——. Poleward limit of trade winds ..... Mean annual isotherm of 68° F. – – – –.

Relatively small areas, in the widest parts of the continents, show true continental conditions.

General Characteristics of Tropical Climates

The most striking thing about the climate of tropical regions is its uniformity. The weather does not change frequently, as in middle latitudes. It is even said that the time of day may be told in some parts of the tropics from the pressure recorded by the barometer. The uniformity of atmospheric conditions day after day, and month after month, is so great that weather and climate are almost the same. Conclusions based on observations for a very few years, or even for a single season in some cases, are nearly as good as conclusions drawn from observations spread over many years. The regularity of weather conditions is occasionally interrupted by hurricanes and typhoons in rather restricted portions of the tropics (p. 138).

Uniformity of Temperatures

The average temperatures of the tropics are even more uniform than other elements of the climate. The lack of great variation depends on two facts: (1) the sun is always nearly overhead, and (2) the length of day and night is always nearly the same. As a result, the amount of insolation never varies much; it is always large, and temperatures are both uniform and high.

Annual changes. Many tropical localities show a range of less than 10° between the mean temperatures of the warmest and coldest months, and a range of less than 15° is characteristic of most tropical lands (Fig. 93). On tropical oceans, and on some tropical lands, the range is insignificant. At Bogota, Colombia, the coldest month is less than 3° cooler than the warmest month. In any locality having a marine climate, the temperature of any one month is about the same as the temperature of any other month. Buitenzorg, on the island of Java, for example, has an annual range of only 1.8°. Toward the edges of the tropical zone, the annual range of temperature is greater, especially inland (Fig. 93). Thus at Nagpur, in the interior of India, Lat. 21° 9′, the range is 27.1°.

Diurnal changes. In many parts of the tropical zone, the difference in temperature between day and night is greater than that between the warmest and the coldest months. The daily range is greatest in dry regions far from coasts. In such places the tempera-

ture often ranges from a minimum of 50° or 60° at night, to a maximum of 120° in mid-afternoon. Since this is several times as great as the range between the warmest and coldest months, it is commonly said that "night is the winter of the tropics." The daily range is much the same day after day.

At most tropical localities having marine conditions, the temperature rarely falls below 70°, or rises above 90°. The temperatures of this zone are seldom below 55°, except at high altitudes, or above 110° (Fig. 93). In some places, however, freezing temperatures have been known at sea-level, as in deserts near the margins of the zone. On the whole, however, the highest temperatures experienced in the tropics are no higher than those experienced every summer in middle latitudes. It is not so much the high temperature, as the *continued high temperature*, which distinguishes tropical climate.

Effect of temperatures. The uniformly high temperatures of tropical latitudes are significant in several ways: (1) Seasonal changes are so slight that they have little influence on life — animal or plant. The likeness of one day to another, and of one month to another, is probably a chief cause of the habit which tropical people have of putting off everything possible until "to-morrow."

(2) In many tropical regions outside the deserts, the high temperatures are associated with high humidity. This means a *high sensible temperature*, which is uncomfortable and injurious in various ways. For instance, sunstrokes and heat prostrations are especially common among

Fig. 93. Map of the tropical regions showing mean annual range of temperatures (solid lines), mean annual maximum temperatures (broken lines), and mean annual minimum temperatures (dotted lines).

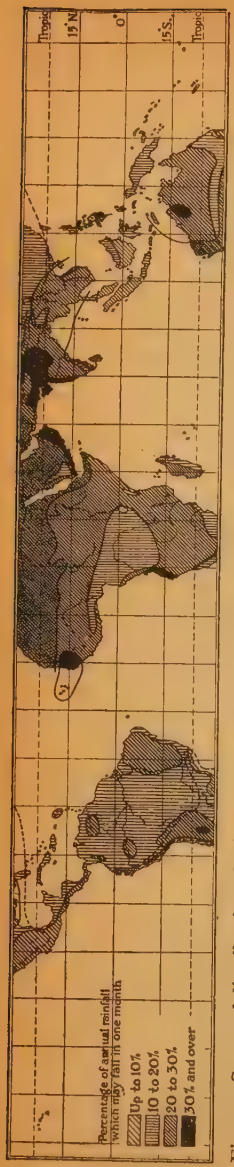

Fig. 94. Seasonal distribution of rainfall in the tropical regions. Dotted areas (North Africa and vicinity and Andes Mountains) have more rain in the winter half of the year than in the summer half. Broken lines represent equatorward limit of snowfall.

white people. The dampness and heat are enervating. This effect is shown in the general laziness of tropical natives (p. 508), and the same trait appears sooner or later in most white people who remain there. The high temperature and humidity are also unhealthful, and together constitute one of the greatest obstacles to the life of white men in this zone. Diseases may be avoided, but in many places there is no relief from the "hothouse" air.

One of the most important results of the high temperatures of tropical regions is that they permit vegetation to grow throughout the year, where rainfall is sufficient. Many trees bear buds, blossoms, and ripe fruit at the same time. The bounty of nature seems unlimited. The effect of this condition on tropical natives is to increase habits of procrastination.

Variability of Rainfall

The *variability* of tropical rainfall is in contrast with the *uniformity* of the temperature. The amount of rainfall varies greatly (Fig. 69), and so does its distribution (Fig. 94). Some places are always dry, and others always rainy. In some places there is no rain for months at a time, and almost daily rains during the rest of the year. Some places have one rainy season a year, while others have two. This variability of rainfall is the controlling factor in the climate where the other leading element, temperature, is nearly constant. In general, the variations of rainfall are definite and regular.

Causes of variation. The amount and distribution of rain in the tropics are determined by the two factors, *winds* and *topography*. The winds (and calms) most important in determining the distribution

of tropical rains are (1) the *trade-winds;* and (2) the *equatorial calms*, between the trade-wind zones. The calm belt moves north and south with the sun (p. 21), and its movements affect the extent and position of the trade-wind belts (Figs. 92 and 95).

The periodic character of rains in much of the tropical zone depends mainly on the apparent migration of the sun north and south of the equator. For most localities within the limits of the migrating belt of calms, the rain comes when the sun is nearly overhead. This type of rainfall might be described as summer rain, though the period of its occurrence is marked, in some places, by temperatures lower than those prevailing at other times. Topography (altitude), especially within the trade-wind zones, is an important factor, for rain is likely to fall from air forced up over high elevations (p. 122). The distribution of land and water also determines, to some extent, the relation of winds to rainfall.

Seasons of rainfall. The monthly distribution of rainfall gives a basis for the division of the year into seasons. This division is twofold for parts of the zone, and fourfold for other parts. Thus some places have two seasons, one rainy and one dry, while others have four seasons, two rainy and two dry. No general statement can be made as to the length of these seasons. Some places with only two seasons have a dry season of eight months and a rainy season of four, while in others these relations are reversed. Hence, the lengths of the seasons in the tropics vary from place to place. Rainfall is here chief among the factors which control the distribution of life, and many of its relations. This is illustrated (1) by the rapidity with which vegetation springs up when rain begins after a long dry season; (2) by the fact that over millions of square miles the planting of crops depends on the coming of rain; and (3) by the fact that even the nesting of many birds takes place only in the rainy season.

Types of Climate within the Tropics

Rainfall and its effects furnish a basis on which different types of tropical climate may be distinguished. There are four principal types: (1) *The equatorial type*, affecting a zone of 10° to 15° on either side of the equator (Fig. 94); (2) *the trade-wind type*, affecting belts outside the equatorial zone; (3) *the monsoon type;* and (4) the modifications due to altitude, giving what may be called *mountain climate.*

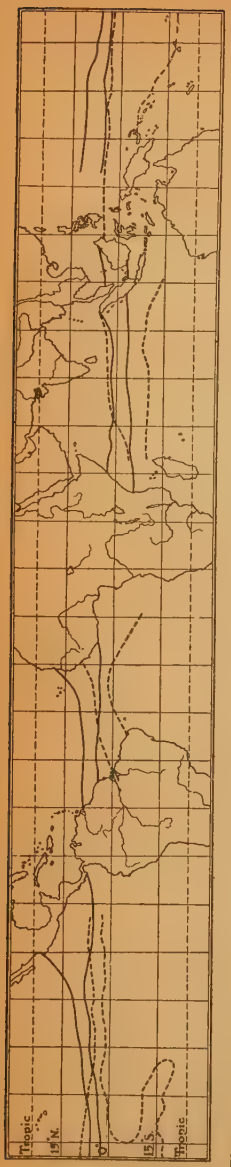

Fig. 95. Map of tropical regions showing migration of belt of equatorial calms. (Diercke.) Approximate limits of calm areas in July ——. Approximate limits of calm areas in January ——.

Equatorial Climates

Temperature. Temperature is least variable in the equatorial part of the tropical zone (Fig. 93). Within the equatorial belt, the differences of temperature depend chiefly on (1) nearness to the sea, especially nearness to that sea from which the wind blows to the land, and (2) altitude. The typical marine climate of this belt has practically no change of temperature from month to month. Thus Batavia, the capital of Java, has a mean annual temperature of 78.8° F., and a yearly range of only 2°. The greatest changes of temperature occur in continental interiors and on high plateaus. Thus in the interior of central Africa (Fig. 93), the mean annual temperature may be the same as that at Batavia, but with a range of 10° or 12° from the warmest to the coldest month.

The daily range of temperature near the equator is almost always greater than the annual range. Quito, Ecuador, Lat. 0° 14′ S., at an altitude of 9,350 feet, has an annual range of less than 1°; but throughout the year the temperature in early morning is about 47°, while at midday it is about 66°. On coasts and islands in similar latitudes, the daily range is much less, say from 90° to 75°. People living under the latter conditions are very sensitive to marked changes of temperature, and for them a temperature below 70° may mean actual suffering. In the equatorial belt, frost on low lands near the sea is unknown. Hence, the development of vegetation is greater here than elsewhere, if other conditions are favorable (Fig. 96).

Rainfall. The rains of the equatorial belt come, for the most part, in daily showers, and, contrary to common opinion, long-continued rains are rare. During even the season of greatest rain, almost every day has a clear morning, and the rain comes from thunder-storms in the afternoon. These thunder-storms result from convection currents in the belt of equatorial calms. In many localities they come with marked regularity at a certain hour in the afternoon,—so regularly, in fact, that in some places social engagements are made to be kept "after the shower is over."

Subdivisions of equatorial climates. The migration of the belt of calms (Fig. 95) involves the movement of the zone of daily thunder-storm rains. This calm belt varies, both in width and amount of migration. In general, it is widest over the lands, 8°–15° of latitude, and narrowest over the oceans, 2°–10°. Its migration usually amounts to 10° or more on land. All places affected by the belt of calms have wet and dry seasons. Two general types of equatorial climate are recognized. The first, known as the *true equatorial climate*, has two rainy seasons and two dry ones, and affects a zone about 10° wide on each side of the equator. The other, commonly known as the *tropical climate*, has one rainy season and one dry season, and affects narrow zones beyond latitudes 10° N. and 10° S. In the area having *the true equatorial climate*, rain is plentiful (Fig. 69). The dry seasons are short, and in most cases not altogether rainless (See Table I below). *The tropical climate* has a short rainy season of three to five months, and a long dry season of seven to nine months (Table II below). Dry seasons of this type may be almost rainless.

The lengths of the seasons and the dates of rain and drought depend on the movement of the belt of equatorial calms. The migration of this belt follows the vertical position of the sun, but lags somewhat behind. Thus, at the equator the rainfall does not reach its maximum at the time of the equinoxes, but a month or more later (April and May, and October and November). Between the two periods of greatest rainfall, there is a time when rain is scanty, or during which, in rare cases, none falls. Bogota, Colombia, shows the typical monthly distribution of equatorial rainfall. This type of rainfall is fairly reliable, for there is little variation in the time of its coming, from one year to another, and the amount which falls is commonly adequate for all needs.

Table I

Equatorial Type of Rainfall (Monthly average in inches)[1]

Bogota, Colombia. Latitude 4° 35′ N. Altitude 8,727 feet.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year[2]
2.7	3.5	4.9	9.6	6.5	3.1	2.6	3.3	2.9	8.4	9.5	5.6	64

Equatorial Type of Temperature

Mean Annual	Coldest Month	Warmest Month	Mean Max.	Mean Min.
57.9°	56.8° (July)	58.6° (March or April)	71.9°	45.8°

The rainfall of the tropical climate, as distinguished from the equatorial, is illustrated by Cochabamba, Bolivia, which has a nearly rainless season from April to November. As a rule, the farther places with tropical climate are from the equator, the shorter their rainy season.

Table II

Tropical Type of Rainfall (Monthly averages in inches)[1]

Cochabamba, Bolivia. Latitude 17° 20′ S. Altitude 8,400 feet.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year[2]
4.2	3.5	2.4	0.4	0.4	0.27	0.19	0.15	0.66	0.59	1.2	3.9	18.1

Tropical Type of Temperature

Mean Annual	Coldest Month	Warmest Month	Mean Max.	Mean Min.
61.5°	55° (June)	66.5° (Oct. or Nov.)	86.3°	27.1°

North of the equator, the rainy season of the tropical climate begins in May or June, and continues until September or October. South of the equator (as Cochabamba), the rainy season begins about November and lasts until March. Since there is no great difference in temperature between the various months of the year, the value of rainfall for crops is about as great at one time as another. On the whole, the tropical rainfall is (1) less and (2) more variable (a) in amount, (b) in time of coming, and (c) in duration, than equatorial rainfall.

Humidity and cloudiness. In the equatorial climate, the humidity is relatively high much of the time. In the tropical climate, the humidity is low during the dry season, and high while the rains last. While high humidity has ill effects on tropical people, as already

[1] Data adapted from Hann, *Handbuch der Klimatologie*, Vol. II.

[2] Total for year includes odd hundredths of inches omitted from monthly figures.

pointed out, it is advantageous locally, for it is an important factor in the formation of heavy dews. Thus, it is said that in some tropical forests the dew is equivalent to a light shower. This is of great benefit where the rainfall is scanty. Cloudiness is rather common, especially where the equatorial type of climate is found. The clouds are formed in the strong convection currents of the belt of calms. Where there are two rainy seasons, there may be cloudiness 70 or 80 per cent of the time. Where there is but one rainy season, as in localities farther from the equator, the long dry season is accompanied by little cloudiness. Tropical climates, as distinct from equatorial climates, are prevailingly sunny.

The distribution of rain and clouds throughout the year affects the temperatures of the different months. As a rule, the end of the dry season has the highest temperature (Cochabamba, Oct.-Nov.), and the rainy season is, in many places, the coolest part of the year, though the sun is then highest. This is due to the fact that the clouds shut off the sun's rays for a considerable part of the day. The increased humidity of the less hot rainy season makes its sensible temperature higher than that of the hotter dry season. In many places, therefore, the rainy season is the most disagreeable time of year. Some tropical diseases are also most prevalent then.

Equatorial climate and life. Because of the climate, the soil of tropical regions is, on the whole, poorer than that of middle latitudes. The high temperatures favor the thorough decomposition of the rocks to form soil, but the heavy daily rainfall, during much of the year, leaches from the soil many of its more soluble and valuable elements.

Fig. 96. Map showing distribution of types of vegetation in tropical lands. (Diercke.)

The high temperature and abundant rainfall, however, give the conditions necessary for a luxuriant growth of vegetation, even on inferior soils, and this growth favors the development of humus, which tends to improve the soil. Dense forests, such as those in the Amazon Valley, in central Africa, in the Malay Peninsula, and on the neighboring islands, are characteristic of the equatorial climate (Fig. 96).

These equatorial forests are inhabited only by relatively sparse populations of backward natives, who live chiefly by hunting and fishing, and by using the abundance of food supplied by the forest (p. 509). Since the rainy season causes floods in the low lands, and drives away many of the animals upon which the natives depend for food, some of the native religious ceremonies contain prayers for a long dry season. The density of the forest makes travel and communication easy only by way of rivers.

The true equatorial climate is unhealthful, especially for white people. Tropical malaria, yellow fever, and intestinal disorders, like dysentery, are the worst enemies which the white man meets near the equator. All these reach their maximum during the rainy season. The first two are spread by mosquitoes, and consequently are associated with swampy places.

Along the Amazon Valley, and especially on the equatorial coast of Africa, fevers practically control the location of residences for white settlers. If the white man escapes these diseases, there is still the climate itself with which he must contend. The never-varying high temperature, and the excessive moisture, month after month, with never any stimulus from invigorating cold, gradually have their effect. The damp air reduces evaporation from the body, and dilution of the blood results. The characteristic tropical anæmia appears sooner or later in most cases, and unless he seeks recuperation in a colder climate, the white man loses his physical and mental vigor.

Effect on transportation and trade. It is necessary to employ a force of men simply to keep the tracks of some tropical railroads clear of vegetation. Many of the wagon roads which are built become impassable in the rainy season. In some regions a mud sledge, hauled by a water buffalo, is used in the wet season, but it is a very primitive and unsatisfactory mode of conveyance.

During the rainy season the rivers are swollen, and travel by boat is easier than at other times, for great sections of country are then flooded. Thus the southern tributaries of the Amazon overflow their banks almost every year, and cover an area as large as the state of Pennsylvania with several feet of water. Habitations are moved to the higher points, but movement from one place to another goes on with ease.

Wooden railroad ties and telegraph poles decay rapidly, and it is necessary, in constructing railroads in parts of the tropics, to use special woods, like camphor

and lignum vitæ, or to substitute iron and concrete. The effect of all these things is to retard commerce. The most favored localities for trade in equatorial regions are those where a large river offers a natural trade route, and the river port is, therefore, the commercial center. Para and Manaos, on the Amazon, are examples of cities developed by river traffic through an equatorial forest. The commodities handled are largely forest products (p. 512).

Tropical climate and life. Where this type of climate prevails, the general absence of rainfall through the larger part of the year leads to vegetation very different from that found nearer the equator. Grass lands replace dense forests (Fig. 96). The *llanos* of Venezuela, the *campos* of Brazil, and the *Sudan* in Africa are the best examples of this type. In general, these regions are without forests, since the short period of growth, limited chiefly to the rainy season, is not sufficient for trees. Scattered patches of forest, however, are found here and there, as in the campos of Brazil.

The people of the grass lands are more advanced than the forest-dwellers of equatorial lands. They derive much of their support from flocks and herds. The necessity of moving frequently to find new supplies of forage for the cattle, goats, or camels, makes many of these pastoral people nomadic.

In favored localities, however, they become permanent settlers, cultivating the soil. Such localities are, in most cases, where irrigation is possible. Outside the irrigated lands, crops are planted in the rainy season only, and only in places where the rainfall is considerable. The latter varies from year to year, and sometimes fails to come at the expected time. This has retarded the development of agriculture, and has led to frequent famines, even among people dependent on their flocks, for the want of new vegetation when the rains fail causes the animals to die of starvation, by hundreds and thousands.

Irrigation, however, may yet make much undeveloped tropical land productive, and on such land, white men may live with more comfort than nearer the equator. The low humidity through much of the year makes the high temperature easier to bear. It means also a greater daily range of temperature, with cooler nights which afford relief from the heat. The tropical type of climate is also more healthful than the equatorial. For all these reasons, the open grassy plains are more suitable for white men. The llanos of Venezuela, the campos of Brazil, and the African Sudan are, therefore, important parts of the tropics, with respect to future development.

Trade-Wind Climate

Winds and temperature. The most striking feature of the trade-wind climate is *the steadiness of the winds*, which blow with a velocity of 10 to 30 miles an hour throughout the year. On the whole, the velocity is somewhat higher in the southern hemisphere, because the larger extent of water surface there means less friction of the moving air. One effect of this steadiness of wind is to make the temperature conditions simple, especially over the oceans, and the climate of islands which lie in the trade-wind zone is about the simplest in the world.

In spite of the simplicity of climatic conditions in the trade-wind zones, both annual and diurnal changes of temperature are greater than in the equatorial belt. Low lands swept by the trades tend to be arid. They are warmed rapidly by day, and cooled rapidly at night, having in many places a diurnal range of 50° or 60°. Temperatures as low as 32° are known. These great changes are felt less than equal changes in the equatorial regions would be, because the humidity is low. The drier air, with its greater changes of temperature, makes the arid and desert lands more healthful than most equatorial regions. The desert climate may be described as almost invigorating, and common tropical diseases practically are absent. The trade-wind zones, therefore, do not present the same kinds of difficulties to human habitation as the equatorial regions. The variations of temperature over the ocean, and near it, are less than in the interiors of continents (Fig. 93).

Rainfall. Though commonly drying winds, the trades contain much water vapor, and become wet winds when cooled to the dew point. They are not so cooled over the lowlands, hence the latter are dry as long as the trades blow. Where they blow throughout the year, a desert is the result (Fig. 69). On the other hand, wherever the trades blow over highlands, the ascending air is cooled, and clouds may form and rain fall. For this reason, the windward sides of highlands in the trade-wind belts are likely to be rainy, while the leeward sides are generally dry (Fig. 69). Thus the leeward (westward) side of the Andes, from Ecuador to northern Chile, presents the strange spectacle of a coastal desert, and a similar condition is found on the leeward coast of southwest Africa. Highlands standing in mid-ocean also have a rainy side toward the trades, and a drier side in the lee, as illustrated by the Hawaiian

islands. Where two islands are separated by a narrow strait, the windward side of one may receive rain every day, while the leeward side of the other, across the strait, is parched and dry.

In Australia (Fig. 97), a continuous highland lies close to the east coast, directly across the path of the southeast trades. The effect of this barrier is to increase the area of the interior desert, sometimes called the "dead heart of Australia," and greatly to restrict the spread of population (Fig. 98). The importance of high lands in getting rain from trade-winds is seen in the fact that even in deserts, as on the Macdonnell ranges in central Australia, and on local elevations in the Sahara, rain falls and vegetation flourishes (p. 504). Streams flow for short distances from the mountains, but soon dry up or are absorbed into the sands of the desert below.

Fig. 97.

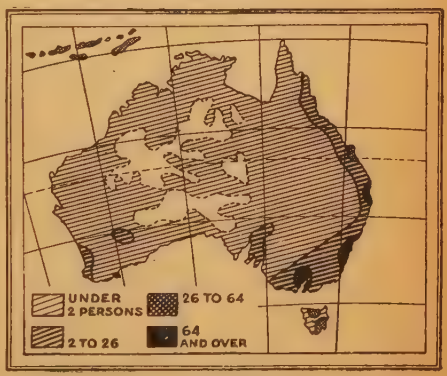

Fig. 98.

Fig. 97. Mean annual rainfall for Australia. (Diercke.)

Fig. 98. Map showing density of population per square mile in Australia. (Lyde.)

Most low lands affected by the trades are, on the whole, sunny; trade-wind deserts are almost cloudless. This fact may have significance in the future, in the possible generation and storage of power derived from the heat of the sun's rays. Cloudiness is confined chiefly to windward slopes, which represent, on the whole, but a small part of the total area of the trade-wind zones.

The time of the rainy season in the trade-wind belts varies from one locality to another. In some places the rainfall is distributed more or less evenly throughout the year, as at Hilo, in the Hawaiian Islands (Table III). In other places it is seasonal, as at Huë, the capital of

Annam (Table III). This variation depends largely on the steadiness of the wind. Places so situated as to get rain from the trade-winds have no rainless season if the winds are fairly steady throughout the year, as in the central parts of the trade-wind zones. Such places usually tend to have more rain when the sun's altitude is lowest, that is, in the winter months. In other places, however, as along the east coast of South America south of the equator, the winter trades are interfered with by cold air moving outward from the interior highlands, and the maximum rainfall comes in summer (São Paulo, Table III). Table III shows three different types of trade-wind rainfall.

Table III

Trade-Wind Rainfall—Windward Coasts.[1] (Monthly averages in inches.)

	Lat.	Jan.	Feb.	Mar.	Apr.	May	June
Huë, Annam.....	16° 33′ N.	4.9	4.3	2.3	1.9	2.2	1.8
Hilo, Hawaii.....	19° 40′ N.	12.7	16.7	11.3	12.0	8.6	7.6
São Paulo, Brazil	23° 33′ S.	10.6	8.4	5.5	3.1	3.2	2.5

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Huë, Annam.....	2.6	5.0	18.1	26.1	24.1	8.2	102
Hilo, Hawaii.....	11.0	11.3	11.3	15.0	11.6	16.2	145.2
São Paulo, Brazil	1.0	1.6	3.2	4.4	4.0	6.3	54.1

Any of these types of trade-wind rain may be complicated by the tropical type, if the station concerned is in a latitude low enough to be reached by the equatorial calms. A locality affected alternately by the trade-wind and the tropical types of rainfall is likely to have two seasons of heavy precipitation — one (tropical) about the time the sun is overhead, the other (trade-wind) about the time the sun is lowest in the sky, — with short, less rainy seasons between.

Trade-winds are interrupted in some places by winds due to seasonal differences of temperature over large land areas (p. 115). When this is the case, a third type of rainfall, the "monsoon" type, occurs in the trade-wind zone. The monsoon rain comes when the sun's altitude is greatest, and when the monsoon winds, displacing the trades, blow to high lands. Hence, it is a summer rain. It commonly occurs in latitudes higher than those where the equatorial type of rainfall is found.

Cyclones of the trade-wind belt. The normal weather conditions of trade-wind belts are interrupted by tropical cyclones. They

[1] Data from Hann, Vol. II, pp. 217 (Huë), 268 (Hilo), and 351 (São Paulo).

appear to originate over islands along the margins of the equatorial belt, and move to higher latitudes through the trade-wind zone (Figs. 82 and 86). These storms are confined almost wholly to the season when the equatorial calms are farthest from the equator. The migration of this belt is both slower and less over the oceans than over the lands. Hence these storms occur only during a few months, usually late summer and early autumn, and at opposite times of the year on the two sides of the equator. They interrupt the regular daily changes of temperature, and in many cases give torrential rains.

The particular importance of the tropical cyclone is in connection with the destruction of life and property by wind and flood. The loosely built native houses offer little resistance to the violent winds. Crops are beaten down by wind and rain, and in many cases the destruction is nearly complete.

Relation of trade-winds to commerce. The steady, reliable trade-winds which prevail over a wide, east-west belt of the oceans have long been an important factor in determining the courses of sailing vessels.

Most sailing routes crossing the equator have been influenced by the trade-winds, and the routes for out-bound and in-bound vessels are different. Thus whaling vessels out-bound to the Pacific from New Bedford (Mass.) commonly crossed the Atlantic to the Cape Verde or Canary Islands before turning south. This practice led frequently to the employment of Portuguese sailors from those islands, and the introduction of a Portuguese population into some of the New England whaling ports. Vessels in-bound from the Pacific usually swing around Cape Horn, far out into the South Atlantic (Why?), and thence sail directly home. Sailing routes are unlike steamer routes, for steamers generally follow about the same course in both directions. The Panama Canal will probably be of little importance to sailing vessels going east, on account of adverse winds. Similarly, the Red Sea presents head winds to a sailing vessel attempting to pass from the Indian Ocean to the Mediterranean.

Trade-wind climate and life. Temperature conditions are almost as favorable for vegetation in the trade-wind zone as in the equatorial belt, but moisture is scanty. Forests as dense as those of the equatorial belt are common on rainy windward coasts or highlands, but most of the lands of this zone are arid (Fig. 96). The Sahara and the desert of Australia are each more than two-thirds the size of the United States. Trade-wind deserts have little vegetation, and, except in oases, no plants of value (p. 499).

Considering the tropical zone as a whole, vegetation decreases in amount from the equator out (Fig. 96). This is illustrated strikingly in Africa, where a broad land area extends beyond the tropics both

north and south of the equator. Near the equator, there is the dense equatorial forest, and on either side of it lie belts of grassy vegetation which are developed best at the north, in the Sudan. North of the Sudan is the Sahara, with little or no vegetation. The few plants of the desert are such as can withstand the dryness (p. 499). Vegetation is so scanty that the people, depending for support mainly on a few animals, have to move frequently from one source of water to another. Native animals show adaptations to their surroundings in respect to color, speed, means of self-protection, and other matters (p. 500). South of the equator, in the area corresponding to the Sahara, the continent is narrow and the land high, so that desert conditions are not fully developed.

Deserts interfere in many ways with travel and communication among men, and a desert is almost as effective as the ocean in presenting a barrier to the spread of plant and animal species (p. 500). Since most beasts of burden cannot stand desert conditions, caravan trade is carried on chiefly with the help of camels (p. 501).

Railroad building across deserts is interfered with in various ways. Wooden ties literally dry up and blow away; blowing sand is likely to cover the tracks; fuel and water are scarce or lacking; and cars must be of special construction to withstand the dryness of the air. Hence problems of travel and communication are difficult, and not one of the many projects for railroads across the great deserts of Africa and Australia has been completed. Such roads would be of great value, because they would connect fertile lands on opposite sides of the desert.

Human life in the desert is influenced greatly by the climate (p. 501). Food and useful materials of all kinds are scarce, yet the greater changes of temperature necessitate more clothing than is needed in the equatorial belt. White clothing is worn commonly, because it absorbs less sun-heat than dark fabrics. The clothing is loose, partly because such clothing is more comfortable in the heat, and partly because the danger of dust-storms makes it desirable to have a covering which can be drawn over the head. The people of deserts usually live in tents, or in loosely constructed, low, flat-roofed houses. There is no need for shutting out cold or rain. Where solidly built, the flat-roof makes a good place to sleep.

Since ordinary fuel is commonly scarce or absent in the desert, the only source of artificial heat, in many places, is the dried dung of animals like the camel. With such a scanty supply of fuel, cooking is of the most primitive sort. This fact leads, in part, to a general diet of curds, milk, etc. Where meat is used, it is often air-

dried, a process made possible by the low humidity. Utensils, like vessels for holding water, are made of leather — about the only serviceable material available in many places.

The use of water for bathing is unknown in many desert localities, because of the scant supply. Even where water is to be had, some of the natives claim that its use makes the body more sensitive to temperature changes. The sand-bath is common.

In parts of the deserts, showers occur now and then. In some places they come regularly at certain seasons of the year, and, in favored spots, the rainfall is enough to grow grain. In the latter case, the rainfall has a marked effect on the customs and religions of the people. In some places, elaborate ceremonies are performed in honor of the rain gods, before the seeds are planted. It is interesting to note, however, that the time for these ceremonies usually is determined by the cleverer persons, who know, better than others, when rains may be expected. In some desert regions, therefore, the worship of rain, of rain clouds, or of the gods supposed to control them, is common. Sun worship is also common in most religions of desert people, as in that of ancient Egypt; for the sun is one of the most prominent things of the desert. Desert conditions, therefore, affect man in many different ways (pp. 501–506).

Monsoon Climate

Rainfall. In some countries, at the season when the sun's altitude is greatest there, the trade-winds are overcome by the tropical monsoon. While the monsoon lasts, it blows in many places with the steadiness of the trades. Since this wind owes its origin largely to a favorable distribution of land and water (p. 115), it is not found everywhere in the trade-wind belts.

Monsoons are well developed in southern and southeastern Asia, especially in India and thence to the China Sea. On the eastern coast of Asia, northward nearly to latitude 50°, there is a somewhat similar oceanic wind in summer, which gives some rain to the land. The time of the tropical monsoon is fairly definite because of its relation to the altitude of the sun. For most places in the northern hemisphere, the monsoon season is between May and October. In the southern hemisphere, especially northern Australia, it is from November to April. The monsoon wind generally brings rain. Over lowlands, the rain results from the strong convection above the hot land to which the wind blows; on the windward sides of high mountains, the rain is much heavier, a fall of 400 to 500 inches a year occurring in some places. Since it all falls in five to six months, this means a daily rainfall of two to four inches throughout the rainy season.

The conditions which produce rain mean increased cloudiness, and so the rainy season may be less hot than the others. As a rule, the highest temperatures occur just before the rainy season begins (Bombay, Table IV), for at this time the regular winds become weak or fail altogether. During the rainy season, the increased humidity more than offsets the comfort which the slightly lower temperatures might afford.

The Indian monsoon is a southwest wind (Fig. 66), blowing from the Indian Ocean and the Bay of Bengal. Western and southwestern slopes therefore receive much rain, but the eastern coast, in the lee of the Deccan plateau and Eastern Ghats, gets little rain while the monsoon blows (Fig. 94). This coast gets its rain when the northeast trade-wind blows. In northwestern India there is a large desert, not reached by the monsoon. Hence different parts of India have different types of rainfall, largely as a result of the relation of wind direction to topography. The larger part of the country, outside the desert, however, has a rainy season from May to October, and a dry season during the rest of the year. This is illustrated by the monthly rainfall averages for Bombay:

Table IV

Monsoon Type of Rainfall[1] (Monthly averages in inches)

Bombay, India—Latitude 18° 54′.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
0.1	0	0	0	0.5	20.78	24.68	15.1	10.78	1.8	0.5	0.07	74.4

Temperature at Bombay[2]

Mean Annual	Coldest Month	Warmest Month	Mean Max.	Mean Min.
79.5°	73° (Jan.)	84.7° (May)	95°	61°

During the dry season, many localities are practically rainless. This season also is sunny, and where the trade-wind is felt distinctly, it may be cool and agreeable. In many places, however, the dry season is hot and disagreeable.

There are no important monsoon districts in the tropical lands of the western hemisphere, because there the arrangement of land and water areas is not favorable for their development. Besides southern Asia, northern Australia (Fig. 97) and the northern coast of the Gulf of Guinea (West Africa) have distinct tropical monsoon climates.

[1] Data from Hann, Vol. II, p. 189.

[2] Data from Hann, Vol. II, p. 174.

Importance of monsoon rains to people. The importance of the monsoon rainfall to southern Asia can hardly be over-emphasized. During the dry season all vegetation withers, and the earth is parched and dusty. Hence the growing of crops, and the support of the people over vast areas, depend on the regular appearance of the rain-producing monsoon.

For one reason or another, these southwesterly winds sometimes fail, and still oftener they do not appear when they should. At still other times, they stop sooner than usual, and finally, they are sometimes interrupted during what should be their proper season. The failure of the rain means loss of crops and famine for the dense populations of the monsoon districts. Famines usually leave hundreds of thousands of people in a weakened condition, so that ravages of epidemic diseases, like bubonic plague and Asiatic cholera, commonly follow a famine. In India, deaths from famine and disease have exceeded a million in many different years. So great has been the loss of life, in some cases, that laborers enough to cultivate the farms were not left. The famine districts are not in the irrigated localities, or in the desert sections of northwestern India, but in the regions of moderate rainfall (30 to 50 inches), where, in normal years, there is water enough for the crops. In other places, especially in southern China, too much rain sometimes produces disastrous results. Rivers rise high above their banks, destroying much property and many lives; and famines, resulting from the destruction of crops, at times cripple whole provinces. Riots in some of the cities of southern China in late years have been traced directly to floods and famines.

Monsoon countries as a whole are populated densely, containing the larger part of the population of the tropical zone. They offer rather easy conditions of life, so far as the requirements of man are concerned, and the soils generally are productive when rains are regular. The crowding of people in monsoon districts is indicated by the fact that 300,000,000 people live in India, in an area less than two-thirds that of the United States.

Altitude as a Climatic Control in Tropical Regions

Effect on temperature. For most of the tropical zone, varying altitude is the one factor which causes important variations in temperature. The extent of this variation is suggested by the fact that tropical mountains exceeding 16,000 feet are snow-capped. Thus the volcano Cayambe, which stands directly on the equator in Ecuador, has permanent glaciers near its summit, at an altitude of about 20,000 feet.

The lower temperatures found at moderate altitudes make plateaus in the tropics more agreeable and healthful than lowlands.

White people living in the tropics seek the highlands, whenever possible, for residence (p. 486). On the Bolivian plateau, for example,

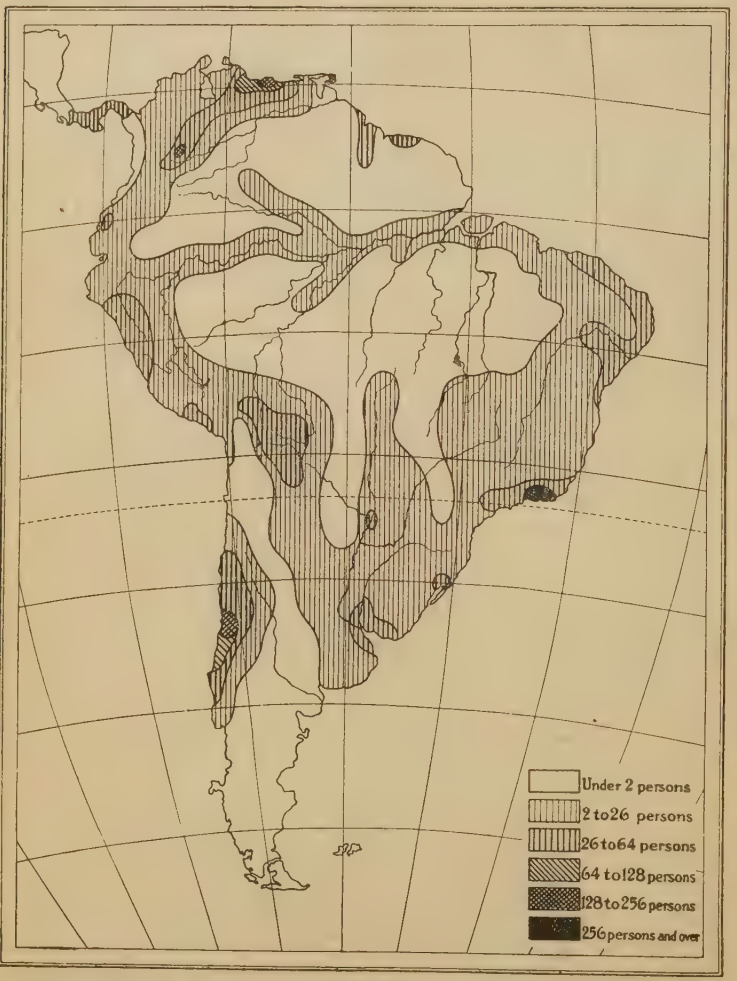

Fig. 99. Map showing density of population per square mile in South America. (Lyde.)

the daily temperature may range from a minimum of 32°, to a maximum of 75° or 80°.

The effect of the lesser heat even at altitudes of 7,000–8,000 feet is not, however, equal to an invigorating cold season, like the winter of middle latitudes. The climate of tropical mountains and plateaus is somewhat like the marine climate of the temperate zones. Both are sometimes spoken of as being like "perpetual spring."

Vegetation affected by altitude. The vegetation, native and cultivated, of the higher altitudes of the tropical zone resembles that at lower levels outside the tropics. For example, on tropical highlands in Bolivia wheat and potatoes are common crops, whereas on most tropical lowlands they cannot be grown at all, or not as profitably as rice. There is a gradual change with increase of altitude, from products like sugar-cane or rice in the lowlands, through a belt of temperate-zone fruits or vegetables at a moderate altitude, to cold-temperate and arctic types of plants, and then to perpetual snow at an elevation of about 16,000 feet. The snow and ice on the heights help to supply water for irrigation below. In places, too, the ice of the high mountains is carried down to settlements below.

Population affected by altitude. The most important effect of the highland temperatures is seen in the distribution of the population. From Mexico to Bolivia, most of the highlands are well populated, and the lowlands sparsely (Fig. 99). The single exception is in Peru, where three-fourths of the people live on the coastal lowland, which is dry and healthful. The effect of altitude appears also in the location of the cities, many of which are found at elevations exceeding 5,000 feet, and some of them are above 10,000 feet, as shown below.

Tropical American Cities at High Altitudes

City	Latitude	Altitude	Population	Mean Temperature Warmest Month	Mean Temperature Coldest Month
Caracas	10° N.	4,000	90,000	73.9°	68.5°
Guatemala	14° N.	4,850	125,000	68.5°	62.0°
Mexico City	19° N.	7,350	350,000	64.5°	53.6°
Bogota	4° N.	8,630	120,000	58.6°	56.8°
Quito	0°	9,350	80,000	56.6°	56.1°
La Paz	16° S.	12,200	70,000	54.5°	45.1°

The temperatures of cities in middle latitudes are in strong contrast with the above:

Philadelphia . . . . . Lat. 39° 56′ N.; warmest month, 75.9°; coldest month, 31.2°
St. Louis . . . . . Lat. 38° 37′ N.; warmest month, 78.0°; coldest month, 31.1°

In tropical America, it is common for the chief city to be on the highland in the interior, and for a smaller city, serving as a commercial outlet, to be on the hot, damp, and unhealthful plain close to the sea. Mexico City and Vera Cruz; Caracas and La Guayra; São Paulo and Santos, are examples of such pairing. Outside the cities, the highlands are the most thickly settled and the best developed sections, while the lowlands have few people, chiefly natives, and are but little developed. The result is that many of the chief products of tropical lands are not truly tropical in character.

The decreased pressure of air which goes with increased altitude is of some importance in the higher tropical lands. It is generally true that the natives living at high altitudes (in Bolivia up to 15,000 feet) have a large lung capacity, on account of the rarefied condition of the atmosphere. These natives are active and well under their natural conditions, but usually sicken if taken to low altitudes. Conversely, natives of lowlands often experience much discomfort at high elevations. The difficulty of keeping native laborers at altitudes of 4,000 to 5,000 feet is said to have retarded the cultivation of coffee in Brazil. In most localities, however, the ill effects of lessened pressure are not felt below 5,000 feet. Hence diminished pressure is not likely to affect seriously the growth of population in tropical highlands.

The Future of the Tropics

Because of their more comfortable temperature and more healthful conditions, the highlands of the tropics will probably be highly developed earlier than the lowlands. At altitudes above 2,000 or 3,000 feet, tropical diseases, particularly malaria and yellow fever, are not prevalent. Civilized peoples can live comfortably at these altitudes, and where they have not already done so, they are likely to establish themselves in lands of moderate height where there is adequate water, and from them direct the development of the adjoining lowlands, the products and resources of which are of so much importance to the commercial world.

Questions

1. What sort of climate would prevail where the Gulf of Mexico and the Caribbean Sea are, if those areas were land?

2. What effect would such a land area have on the climate of northern South America and Central America?

3. In what respects would weather forecasting in Brazil differ from weather forecasting in the United States?

4. Why do annual temperature ranges increase toward the margins of the tropics? Why are the highest temperatures not found along the equator?

5. Why is it advisable for white men in the tropics to wear clothing of different weights in midday and evening?

6. Explain the necessary relation of a place to the equatorial belt of calms, in order that it may have two distinct rainy seasons and two distinct dry seasons.

7. Classify the different sections of tropical America under the types of climate given on page 161.

8. Why is there no desert in that part of tropical South America east of the Andes?

9. Suggest ways in which tropical climates might affect the character of imports from the outside world.

10. What changes would be produced in the climate of Australia if the main mountain range stood along the west coast instead of along the east coast?

11. Which of the two important tributaries of the Nile is the first to be in flood each year? Why? Which has the greater flood?

12. Suggest reasons which might delay the arrival of the Indian monsoon.

13. What relation does the warmest month at Cochabamba bear to the summer solstice for the southern hemisphere (p. 162)? How does this compare with conditions in the latitude of Chicago? Explain the difference.

14. Explain the distribution of rainfall in Australia (Fig. 97).

15. What industries are likely to be connected with the distribution of population and rainfall shown in Figs. 97 and 98?

16. Explain the course of the line showing the poleward limit of palms in Fig. 92.

17. Why do some areas in the tropics (Fig. 94) have more rainfall in the winter than in the summer half-year?

18. What reasons account for the scanty population in the interior of Brazil (Fig. 99)? Compare Fig. 99 with Figs. 69, 93, and 96.

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CHAPTER X

TYPES OF CLIMATE IN THE TEMPERATE (INTERMEDIATE) ZONES

Areas Affected

Extent of temperate zones. The two temperate (or *intermediate*) zones lie on either side of the tropical zone. Defined by latitude, their equatorial limits are the parallels 23½° N. and S. respectively, and their poleward limits the polar circles, 66½° N. and S. There is, however, no marked change in climate as these boundary lines are crossed. The intermediate zones contain a little more than half (52.7%) the area of the earth.

Southern hemisphere. Land and water are distributed very unequally in the temperate zones. In the southern hemisphere, water prevails (Fig. 100), but the zone covers parts of Africa, South America, Australia, and various islands, of which Tasmania and New Zealand are most important.

The largest land area in the south temperate zone is in South America, about one-fourth of the continent (or about 1,800,000 square miles) being south of the Tropic of Capricorn. This area includes most of Argentina and much of Chile, and supports about one-fourth of the population of the continent (about 10,000,000 people).

More than half of Australia is south of the Tropic of Capricorn, but so much of it is arid that it is less important than the corresponding part of South America. About three-fourths of the people of Australia (more than 3,000,000) live in this zone. New Zealand, little more than 100,000 square miles in area, has a population of about a million.

Only about 7 per cent of Africa lies south of the Tropic of Capricorn. This area of 700,000 to 800,000 square miles has a population of 5,000,000 to 6,000,000, hardly more than 4 per cent of the population of the continent.

The total land area of the south temperate zone is only about

4,000,000 square miles, and its population not more than 20,000,000. In other words, the lands of the south temperate zone, taken together, have an area about one-third larger than that of the United States, and a population less than one-fourth as great.

The area of ocean in the south temperate zone is about twelve times as great as that of the land. Hence much of this zone has a marine climate. The climates of the south temperate zone, too, resemble those of the tropical zone more than do those of the north temperate zone.

Northern hemisphere. The proportions and distribution of land and water in the north temperate zone (Fig. 101) are very unlike those in the south temperate zone. In the former, the area of land (26,000,000 square miles) is about equal to that of water. Furthermore, the continents are broader in high latitudes, and narrower toward the equator. The north temperate zone contains nearly as much land as all the other zones combined. In North America, it includes all of the United States except the northern part of Alaska, most of Canada, and part of Mexico. Nearly all of Europe, most of Asia, and part of northern Africa lie within it. It contains the greatest nations and the majority of civilized people. Because of its greater expanse of land, continental climates are more prominent than in the southern hemisphere. Hence, the two zones differ greatly in the details of their climates. Only in certain broad aspects can they be discussed together.

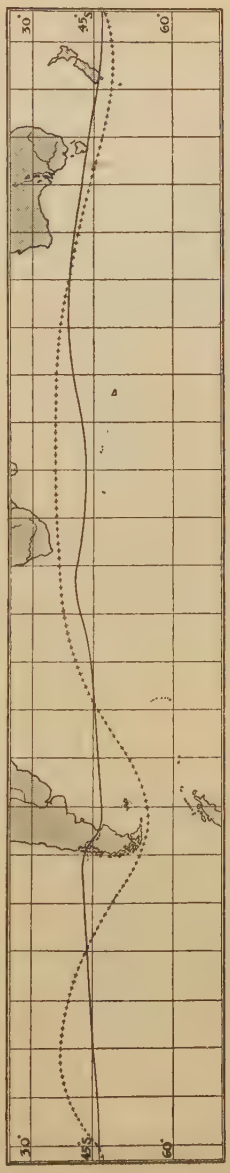

Fig. 100. Map of South Temperate Zone, showing land and water areas. Poleward limit of permanent habitations +++++. Isotherm of 50° for warmest month ——. Poleward limit of cereals, about latitude 45° in South America.

Fig. 101. Map of North Temperate Zone, showing land and water areas. Poleward limit of cereals ———. Poleward limit of permanent habitations + + + + + (in Greenland). Isotherm of 50° for warmest month ———.

General Characteristics of Climates of the Temperate Zones

Variability. There are several types of climate in these zones, and their differences are perhaps as striking as their likenesses. Variability is the distinguishing feature of most of them. The climates vary greatly (1) in temperature, (2) in direction and velocity of wind, and (3) in amount and distribution of rainfall. In general, the variability is less in the south temperate zone than in the north temperate zone (Why?).

Sun influence. The fundamental cause of variability, as contrasted with the uniformity of tropical climates, is found in the great variation in the altitude of the sun and in the length of day and night. The sun never is overhead within these zones, and during at least a part of the year it is many degrees below the zenith at noon (pp. 20–21). There are, accordingly, marked differences in the amount of heat received at different times, and the year is divided naturally into seasons which vary much in temperature.

Influence of variable winds. The prevailing (westerly) winds of these zones are much less regular in direction and velocity than the trade-winds of the tropical zone, and are interrupted, modified, or overcome entirely for a time, by cyclonic storms. The latter vary greatly in frequency and strength.

Weather and climate. In the temperate zone, weather and climate are entirely different. In summer, the weather often resembles that of the tropics. Then diurnal changes (p. 78) are interrupted

least by storms. The temperature may show a regular rise and fall day after day, and convectional showers may appear in the afternoons. These and other minor features, as diurnal changes of pressure and wind velocity, are similar to those of the tropics. Cyclonic storms, however, may be important weather controls even at this season. In winter, diurnal changes are interrupted frequently, for then the chief control of weather is the movement of storms (p. 136). Their coming causes changes of temperature, changes from clear to cloudy skies, and changes from dryness to rain or snow. In the intermediate seasons, there is a gradual transition from one control (diurnal) to the other (cyclonic). Thus, as spring comes on, the cyclonic-storm control gradually weakens, and the diurnal control becomes stronger. In the autumn, the diurnal control is interrupted more and more frequently as the cyclonic-storm control becomes steadily stronger.

Temperature ranges. The factors noted above lead to great variability of temperature from day to day, from year to year, and from place to place. The great and sudden variations of temperature make the term *temperate* somewhat inappropriate for these zones. The weather at least is often most intemperate. In contrast with the conditions in the tropical zone (p. 156), observations through many years are necessary to get a correct idea of the climate of a given locality in the temperate zones. In the temperate zones, the yearly range of temperature (Fig. 102) is greater than the daily range in almost every locality.

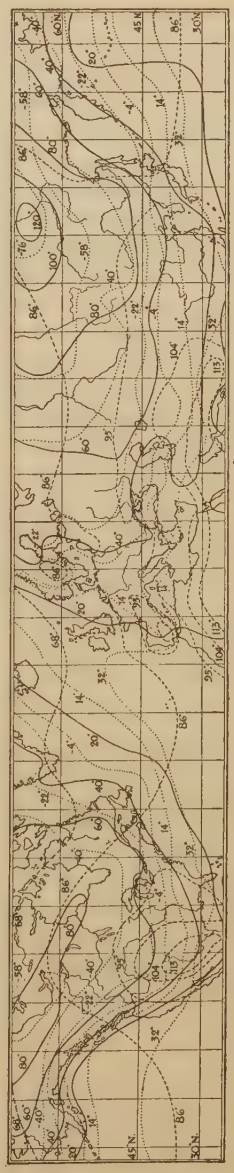

Fig. 102. Map of North Temperate Zone, showing mean annual range of temperature (solid lines), mean maximum temperatures (broken lines), and mean minimum temperatures (dotted lines).

In the same latitude, conditions vary widely from place to place, both with respect to variation of temperature, and the time of greatest heat and cold. Far inland, the highest and lowest mean temperatures of the year ordinarily occur about a month behind the highest and lowest noon-altitudes of the sun, and may differ by 50°, even in middle latitudes (as at Chicago). Spring and autumn are much alike so far as temperature is concerned. Near the sea, the highest and lowest temperatures are about two months behind the sun, while spring is cold and autumn is warm. The maximum temperatures in summer (Fig. 102) in many cases exceed those of some tropical stations (Fig. 93), and the lowest temperatures in winter approach polar cold (Fig. 112). The average annual range, however, is as low as 20° in some places, even in comparatively high latitudes. Hence, latitude is not a sure index of climate in this zone.

South temperate zone. The limited extent of land in the south temperate zone gives it a climate less variable than that of the corresponding northern zone. The lands of the temperate zone in South America, for example, have a range in latitude of more than 30°, but the difference in mean temperatures, between the extremes of latitude, is less than 30°, as shown below.

	Lat.	Mean Annual	Warmest Month	Coldest Month
Asuncion	25° 16′	71.7°	78.8°	62.7°
Punta Arenas	53° 10′	43.3°	50°	35.4°
Difference		28.4°	28.8°	27.3°

This difference between Asuncion and Punta Arenas is as great as any to be found in settled portions of the south temperate zone.

North temperate zone. In the northern hemisphere, on the other hand, the great expanses of land, and their extension into high latitudes, lead to marked contrasts in temperature between the two margins of the zone. In many places the differences are nearly twice as great as those of the southern hemisphere. The temperatures of Matamoras, Tex., and Norway House, Canada, afford a good contrast, since these stations are in latitudes corresponding to those in South America, cited above:

	Lat.	Mean Annual	Warmest Month	Coldest Month
Matamoras	25° 50′	73.7°	84.7°	60°
Norway House	53° 50′	28.4°	63.5°	7°
Difference		45.3°	21.2°	53°

Some of the highest as well as some of the lowest known temperatures occur in this zone (Fig. 102). Temperature ranges also vary greatly. The mean annual range of temperature in North America, for example, varies from as little as 16° in southern California (San Diego, near the sea), to as much as 81° in northwestern Canada (Fort Chippewyan, far from the sea to windward).

Temperature and seasons. The variations of temperature in the intermediate zones give four seasons, which are more distinct in the northern hemisphere than in the southern. Near the tropical margins of these zones, summer and winter are less unlike than elsewhere, and the intermediate seasons, spring and autumn, are long. Toward the poleward margins of these zones, on the other hand, differences between summer and winter are great (especially in the north), and the transition seasons are short. Hence the length of the growing season for plants differs greatly in different parts of the zone, with important effects on life.

Seasons and rainfall. The variations of temperature are accompanied by variations in rainfall. In tropical lowlands, where temperatures always are high, it makes little difference to vegetation when rain comes; but where there are seasons of radically different temperatures, rain is useful to plants in summer, but not in winter. There are two general types of seasonal rainfall in the temperate zones, the *marine or winter type*, and the *continental or summer type*. In general, windward coasts have the winter type of rainfall, while interiors and leeward coasts have the summer type.

Effect of seasons on life. Both the variations of temperature and the distribution of rainfall have far-reaching effects on life, some of which may be pointed out. Civilization, which apparently began close to the tropics, has moved steadily outward (especially northward), until its chief centers are now in the middle latitudes of the northern hemisphere (p. 179). Here the seasons are commonly regarded as responsible for much of the energy, thrift, and industry which have brought about this advanced development. Seasonal variations of temperature are better for human development than the monotonous heat of tropical regions, or the depressing cold of polar regions.

The changes of seasons stimulate effort. In summer, conditions of existence in many parts of the temperate zones are almost as easy as in tropical regions. Summer is a time of abundance, and winter is a time of scarcity in Nature's supplies. In summer, it is necessary

Fig. 103. Seasonal distribution of rainfall in the North Temperate Zone. Dotted areas have more rainfall in autumn and winter; other areas have more in spring and summer. Broken line shows equatorward limit of snow. (After Supan.)

to provide food, clothing, and shelter for winter, when nature does not provide. In order to live, therefore, man must plan for the future, and to secure the things he needs requires regular effort. Life is, as a rule, neither too easy nor too hard. Careful planning and steady labor make it possible for man to secure what he needs. These conditions lead to mental, physical, and industrial development, and such development is the basis for advance in civilization.

Types of Climate

As already noted, the temperate zones have various types of climate. The north temperate zone especially is a patch-work of climatic types, whether the division is based on temperature or rainfall. The south temperate zone, with its smaller land areas, mostly near the sea, has few important types of climate. In the southern hemisphere, also, the westerly winds are developed better, because of the greater expanse of water there.

The chief climatic types of both hemispheres are determined by (1) distribution of land and water, (2) winds, and (3) altitude. With insolation, these factors control the temperature and rainfall. On this basis, the following important types of climate are recognized: (1) That of *windward coasts in low latitudes*, or the *sub-tropical type;* (2) that of *leeward coasts in low latitudes;* (3) that of *windward coasts in high latitudes* (above 40°); (4) that of *continental interiors*, a type which varies much, especially in amount of rainfall; and finally, (5) the modifica-

tions, particularly of the continental type, brought about by altitude.

1. THE CLIMATE OF WINDWARD COASTS IN LOW LATITUDES (BELOW 40°)

General characteristics. The chief features of this type of climate are moderate temperatures, with small annual (Fig. 102) and large diurnal range. In these respects the climate resembles that of the tropics. The rainfall is rather light in most places (Fig. 69), but not in all, and is greatest in autumn and winter (Figs. 103 and 104). The summers are dry. This climate is typically sunny, usually with a maximum of cloudiness in winter. Winds are the chief control.

Distribution. The sub-tropical type of climate is found at and near the equatorward margins of the temperate zones, in latitudes affected alternately by the trade-winds, the tropical belts of high pressure, and the westerly winds. This type of climate is developed best on islands and on the western (windward) coasts of continents between the parallels of about 25° and 40°. It prevails over much of the land of the south temperate zone (Fig. 104), and affects extensive areas in the north temperate zone. It is widespread about the Mediterranean Sea, extending from Spain on the west through Italy and the southern part of the Balkan Peninsula into western Asia, as well as across the northern part of Africa. The wide extent of the sub-tropical climate about the Mediterranean has led to the name "Mediterranean climate."

In North America, the sub-tropical type of climate is almost confined to the

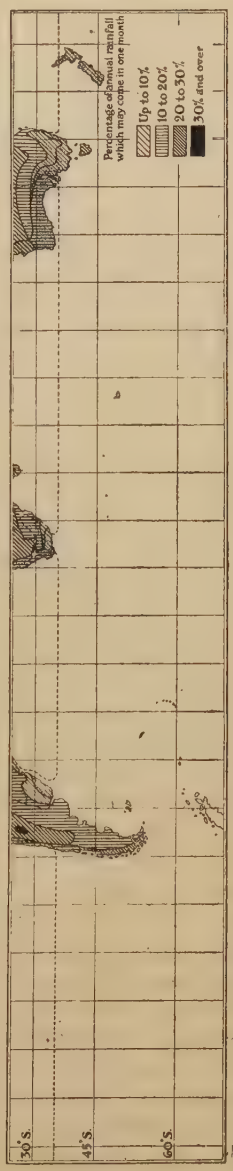

Fig. 104. Seasonal distribution of rainfall in the South Temperate Zone. Dotted areas have more rainfall in autumn and winter; other areas have more in spring and summer. Broken line shows equatorward limit of snow. (After Supan.)

coastal part of southern California, south of San Francisco. The climate of this region may be taken to illustrate the type.

The southward migration of the wind systems in winter brings southern California under the influence of westerly winds. The northward migration of the wind systems in summer brings this region under the influence successively of (1) greatly weakened westerlies, (2) the tropical high-pressure belt, and (3) the northern margin of the trade-winds.

Temperatures. This succession of winds gives moderate and fairly uniform temperatures (Table I). The latitude is high enough to prevent a long continuation of temperatures as high as those of the tropics, and nearness to the sea prevents the seasonal extremes characteristic of most places in the temperate zones (Fig. 102). Freezing temperatures occur but rarely in low altitudes. The small daily ranges of temperature are greater than the yearly ranges. On the whole, the temperature of southern California is much like that of tropical lands at moderate altitudes.

In some respects the sub-tropical type of climate is the best in the world, and is described frequently as being like "perpetual spring." It is healthful, as indicated by the popularity of southern California, where Pasadena, Riverside, San Diego, and other cities duplicate, on a small scale, the noted resorts in the Riviera of southern France and Italy. The sunny skies (68 per cent for San Diego) are an important factor in the popularity of these places, especially in autumn, winter, and spring. The dry season (summer) may be disagreeable because of (1) high temperatures, (2) the drying up of vegetation, and (3) the prevalence of fogs and dust. Numerous stations in California have less sunshine in the dry season than in the rainy season, on account of fogs. In many places it is chilly and disagreeable, at the height of the rainy season.

The temperatures of San Diego, Cal. (Table I), are typical for western coasts in the sub-tropical zone. The absolute lowest temperature at San Diego is 32°, and the absolute maximum 101°. Such variations are characteristic of tropical districts where the *average* annual range is not more than 15° or 20°. Interior stations, like Needles and Bakersfield, show greater average ranges and more marked extremes, because they are farther from the sea, with mountains between. The mean maxima are higher, the mean minima are lower, and the frequency of both high and low temperatures much greater.

Table I

Sub-Tropical Climate—Mean Monthly Temperatures

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Average for Year
San Diego	32° 43′	54°	56°	62°	68°	66°	59°	61°
Eureka	40° 48′	47°	48°	52°	56°	56°	51°	52°

Ranges and Extremes of Temperature

	Lat.	Mean Ann.	Jan.	July	Mean Max.	Mean Min.	Abs. Max.	Abs. Min.
San Diego	32° 43′	61°	54°	70°[2]	71°	54°	101°	32°
Needles[1]	34° 50′	73°	52°	94°	85°	60°	116°	23°
Visalia[1]	36° 20′	61°	44°	80°	78°	45°	113°	17°
Santa Cruz	36° 57′	58°	51°	64°	69°	42°	108°	22°
Eureka	40° 48′	52°	47°	56°	67°	39°	85°	20°

Rainfall. As in most similar localities (Fig. 69), the precipitation is rather low in southern California (Table II below), with a marked winter maximum. The summers are almost rainless for a period which varies considerably from place to place. Thus, San Diego (Table II) has four months (June to Sept.) with very little rain, while Eureka, farther north, has but two such months (July and Aug.). The interior valley of California is dry at all times, because the coast ranges have taken the moisture from the winds from the ocean. The dryness increases the range of temperature in the valley. In northern Egypt, in similar latitudes, the rainless season lasts nearly eight months, while sub-tropical islands, like Madeira, Lat. 32° 38′, may have a dry season (with some rain) of only two or three months. The distribution of rain in subtropical latitudes therefore varies widely.

Table II

Sub-Tropical Climate — Rainfall (inches)

	Jan.	Mar.	May	July	Sept.	Nov.	Year
San Diego	1.6	1.4	0.4	0.1	0.1	0.9	9.4
Santa Cruz	5.0	4.0	1.0	T	0.5	2.7	26.8
Eureka	7.6	6.2	2.8	0.1	1.4	5.4	45.8
Needles	0.6	0.2	0.1	0.4	0.1	0.2	2.7

T = trace of rainfall.

[1] Interior stations, to show contrast.

[2] August mean.

Extremes of Rainfall (inches)

	Mean Ann. Rainfall	Total (driest year)	Total (wettest year)
San Diego	9.4	4.3	27.5
Santa Cruz	26.8	14.0	44.3
Eureka	45.8	30.9	59.5
Needles	2.7	1.8	4.7

Rainfall and crops. During the rainless season, most vegetation dries up unless irrigation is practiced. Where water is available, the abundance of sunshine and the favorable temperatures lead to extensive irrigation, as in southern California, and in the favored parts of southern Europe, western Asia, and northern Africa. Most of the crops of these latitudes, however, are grown during the rainy winter season, and are harvested in spring, before, or soon after, the beginning of the dry season. Winter crops are made possible by the temperatures of that season. Winter wheat is a common cereal crop in Italy, southwestern Australia, and California, while barley, resistant to both heat and dryness, was long the chief cereal in such climates. Corn cannot be grown without irrigation, for it needs a high temperature (such as that of the dry season) during growth.

The characteristic crop of the sub-tropical climate is fruit. Oranges, lemons, olives, dates, figs, and grapes are produced abundantly in southern California, the Mediterranean lands of Europe, north Africa, and Asia Minor. There is possibility of frost, however, and frost-fighting is an important part of the business of the California fruit-grower. In many sub-tropical localities, fruit-drying is an important industry, favored by the dry, sunny weather which follows the ripening of the fruit.

2. CLIMATES OF LEEWARD COASTS IN LOWER LATITUDES

Rainfall. Leeward coasts in the temperate zone between latitudes 25° and 40° have a climate very different from that just described. (1) Rainfall is heavier; (2) there is more rain in summer than in winter (Fig. 103); and (3) there is no pronounced dry season. There are occasional droughts, but they are not of regular occurrence, and are rarely severe. On the eastern coasts, most of the summer rains are associated with oceanic winds, and are of the thunder-storm type. Cyclonic storms also give some rain in summer, and are the principal cause of winter rains. Southeastern United States and southeastern

Asia receive occasional downpours in late summer and early autumn, from tropical cyclones.

Temperature. The eastern coasts also differ from the western in having greater ranges of temperature, both daily and seasonal. Table III gives monthly data for Charleston, S. C., and, by way of contrast, for San Diego.

Table III

Leeward Coast—Low Latitudes

Temperature

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Year
Charleston	32° 47′	50°	58°	73°	82°	76°	58°	66°
San Diego	32° 43′	54°	56°	62°	68°	66°	59°	61°

Rainfall (inches)

	Jan.	Mar.	May	July	Sept.	Nov.	Year
Charleston	3.6	3.8	3.6	7.4	5.5	3.0	53.4
San Diego	1.6	1.4	0.4	0.1	0.1	0.9	9.4

In southeastern United States, sudden and extreme changes of temperature are especially frequent in winter. The contrast between southern California and South Carolina (in the same latitude) is due to the fact that the temperature of the eastern coast is not affected so much by winds from the ocean (Why?). At San Diego the lowest temperature recorded is 32°, and this but once in ten years. At Charleston, the lowest temperature recorded is 7°, while temperatures below 32° occur many times every year. Even as far south as Tampa, Lat. 27° 57′, freezing temperatures occur in most years. This greater frequency of temperatures below freezing is due to anticyclones (p. 136). For the farmer and fruit-grower of Florida and the Gulf district, frost is an even more serious factor than in California.

The eastern coasts of southern continents suffer much less from frosts than those of the northern hemisphere. This is because in the southern hemisphere there are no broad land masses in higher latitudes, from which cold winds may blow to lower latitudes.

The summer temperatures of leeward coasts in low latitudes are much like those of equatorial regions. The day-time temperatures are in many cases fully as high as in the tropics, and there is less relief at night, since the nights are shorter in the higher latitudes at this season. The humidity also is high (Fig. 44), owing to the summer rains; consequently, the sensible temperatures are much higher than those

of the dry sub-tropical climates. These conditions are shown by contrasting Charleston and Savannah with Para, Brazil:

	Lat.	*Warmest Month* Mean Temp.	Mean Max.	Mean Min.	Humidity
Para, Brazil.....	1° 30′ S.	79.5°	93.2°	71.6°	84%
Charleston.....	32° 47′ N.	82°	88°	76°	79%
Savannah.....	32° 3′ N.	82°	90°	74°	82%

Effect on life. Near the equatorward margins of the areas having this type of climate, conditions favor the production of sub-tropical or even so-called tropical crops. Sugar-cane, rice, and cotton are common products of the southeastern coastal lands of the United States, and cotton of the interiors. In this part of the United States, for example, is the greatest cotton belt in the world (p. 547), but while the cotton plant of the tropics may produce for some 20 years, the cotton plant of these latitudes is killed by frost every year (Fig. 109). The corresponding section of southeastern Asia produces much rice. Some sub-tropical fruits also grow in the more favored sections of the east coasts. Thus Florida grows many oranges. Forage crops will grow in a large part of southeastern United States for ten or eleven months in the year; hence it is a region in which some phases of the dairying industry might be developed highly.

The abundance of rain on eastern coasts favors the development of swamps. Where there are high temperatures, these swamps invite diseases like those of equatorial regions (malaria, yellow fever, etc.). The home of malaria in the United States is on the low plains and in the river valleys along the eastern coast south of New York (p. 460). Tropical diseases have been brought into these sections and have become established there during the hot, damp season. Thus yellow fever has been introduced many times into the Gulf and South Atlantic ports of the United States from the nearby tropics, but it never lasts from one summer to the next, on account of the frosts in winter (Fig. 109).

The effect of this climate on people resembles that of equatorial climates. The enervating effects of heat and humidity are obvious. Work in the fields, through much of the year, is not agreeable to white men; hence climatic conditions favored the development of slavery in the southern states. The mild winters, however, attract many people who seek to escape the rigor of more northerly latitudes.

3. CLIMATE OF WINDWARD COASTS IN HIGH LATITUDES (ABOVE 40°); MARINE CLIMATE

Location. The marine type of climate in the temperate zone is confined to islands and windward (western) coasts above the 40th parallel. It is controlled by prevailing westerly winds blowing almost constantly from ocean to land. The transition from the sub-tropical climate (p. 185) to the marine type is gradual, and in certain respects they are not very unlike.

In the western hemisphere, the marine type of climate is developed best (1) from San Francisco to the Arctic Circle, and (2) in Chile, south of latitude 40°. In North America, it is confined to the area west of the Cascade, Klamath, and Sierra Nevada mountains, and is modified greatly east of the low coast ranges. In Chile, it does not extend east of the Andes Mountains (Fig. 104).

In the eastern hemisphere, it does not appear in South Africa or Australia, because neither extends into high enough latitudes. It affects parts of Tasmania and most of New Zealand. In northwestern Europe it affects the coast from France to the Arctic Circle, and extends far inland, because there is no continuous north and south mountain range to extract moisture from the westerly winds. Hence the transition from marine to continental conditions is very gradual, and the influence of the sea is felt almost to the Russian frontier. From the British Isles eastward through Germany, the annual rainfall decreases gradually, the winter maximum is replaced by spring and summer maxima (Fig. 103), and the ranges and extremes of temperature become more marked (Fig. 102). The tempering effect of the westerly winds on the climate of western Europe is the more pronounced, because of the relatively high temperature of the central and eastern parts of the North Atlantic Ocean.

Temperatures. The variations of temperature are less than in the same latitudes elsewhere (Fig. 102). Thus, the yearly range of temperature even in high latitudes (as Sitka, Alaska, Lat. 57°) may be as little as 25°, a range hardly more than that in some parts of the tropics. Thorshaven, in the Faroe Islands, Lat. 62°, has a range of only 14.2°. In this respect the marine climate in the temperate zone resembles the sub-tropical type, though the actual temperatures are lower (Why?). Astoria, Ore. (Table IV), furnishes a good example of the temperatures of this type of climate — the only really *temperate* climate of the intermediate zone.

Table IV

Marine Climate—Temperature and Rainfall

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Year
Astoria, Ore. . . .	46° 11′	41°	46°	54°	61°	59°	47°	52°
Rainfall, inches..		11.1	7.7	4.1	1.1	3.7	11.8	78.2

Interior Climate—Temperature and Rainfall

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Year
Moxee Wells,[1] Wash.	46° 2′	30°	42°	58°	71°	59°	39°	50°
Rainfall, inches.		1.9	0.5	0.9	0.1	0.4	1.3	8.9

Regions having a marine climate have mild winters and cool summers, and their average yearly temperatures are higher than the average of other regions in the same latitude. For example, Ireland, which represents perhaps the extreme case, is 30° or 40° too warm for its latitude, 55° N. Another contrast is found in comparing Sitka, Alaska, with Nain, Labrador, in about the same latitude, and with Philadelphia, in a much lower latitude near the leeward coast:

	Lat.	Mean Temp. Jan.	Mean Temp. July	Ann. Range
Sitka, Alaska, west coast. .	57° 3′	30.2°	54.5°	24.3°
Nain, Labrador, east coast.	56° 33′	7.2°	48.3°	41.1°
Philadelphia, east coast. . .	39° 56′	32°	76.0°	44.0°

Rainfall. Places freely exposed to westerly winds have abundant rainfall during that part of the year when the land is cooler than the sea. This means a dry (but not rainless) summer (Figs. 103 and 107) where lands are low, though the dry season is much shorter than in lower latitudes (Why?). High western coasts have abundant rainfall, high humidity, and cloudiness all the year. In some localities fogs occur almost daily, and in extreme cases, as along the coast of Alaska, they may persist for weeks at a time. A typical development of these conditions is found on the coasts of Oregon (Astoria, Table IV) and Washington, where the heaviest recorded rains of this country occur. The precipitation at Glenora, Oregon, averages 136 inches. The humidity always is high (Fig. 44), the mean annual cloudiness is 75 to 80 per cent (Fig. 50), and evaporation is extremely low (Fig. 43). The typical marine locality is cool, damp, and rainy.

Though the maximum precipitation is in winter, little of it is in the form of snow, except at high altitudes. In this respect west

[1] Near North Yakima, Wash., about 250 miles from the coast.

(windward) coasts are in contrast with east (lee) coasts (Table V), where places as far south as Baltimore receive much more snow than places in corresponding latitudes on the western coast (Fig. 110).

Table V

Snowfall (Monthly averages in inches)

	Astoria Lat. 46° 11′	Eastport, Me. Lat. 44° 54′	Philadelphia Lat. 39° 56′
November	0.3	7.4	1.0
December	1.0	12.9	3.3
January	3.5	15.9	6.1
February	2.2	18.6	7.7
March	1.1	13.5	3.7
April	0.0	8.1	0.4
Year	8.1	77.4	22.2

The contrast between the summer rainfall of the temperate and the sub-tropical parts of western coasts is illustrated well on the Pacific coast of the United States, which shows an increasing amount of rain in summer to the northward. At San Diego, Lat. 32° 43′, typical sub-tropical conditions are illustrated by a total rainfall of 0.4 in. from June to September; Santa Cruz, Lat. 36° 57′, has 0.7 in.; Eureka, Lat. 40° 48′, 2.8 in.; while Astoria, Lat. 46° 11′, has 9.4 in. during the same months. San Diego during six months (May to October, p. 187) has hardly more than one inch of rain. In Eureka, two months (June and July) are nearly rainless, but at Astoria the rainfall of no month averages as low as one inch (p. 192). Astoria has as much rain during its driest month, as San Diego has in its driest six months.

Effect on life. The combination of cool summers, abundant moisture, and much cloudiness, prohibits the growth of many kinds of crops. For example, in the typical marine localities of western North America and northwestern Europe, wheat and corn are not grown. Wheat requires a dry, sunny harvest season, and so its growth near the coasts under consideration is confined to localities where topography modifies marine conditions, as in eastern Washington and eastern England. Corn needs a higher temperature and more sunshine than the marine climates afford. Oats, rye, and barley, however, are grown successfully in a cloudy, damp climate. This is perhaps the chief reason why oats have furnished the staple food of Scotland. Various crops are grown close to the northern limit of the intermediate zone in northwestern Europe and in Alaska. Thus in Norway, rye, oats, barley, and potatoes are grown successfully within the Arctic Circle. In Alaska, barley, potatoes, cabbage, and turnips have been grown at Ft. Yukon, Lat. 66° 30′. The marine climate is also favor-

able for grass, which in some localities grows ten or eleven months in the year (Fig. 109). For this reason, the raising of live stock is or may be important in this climate. In the British Isles, for example, the grazing industry has long been the leading phase of agriculture. Mild temperatures and abundant moisture make Ireland always green (Emerald Isle), and the raising of cattle is a chief industry.

Marine climate also favors the growth of heavy forests, which must be cleared before the land can be cultivated, and the clearing is difficult and expensive, in many places costing as much as $100.00 per acre, after the valuable timber is cut. Good examples of such forests are found in northwestern United States (p. 557). Northwestern Europe was originally well forested under similar climatic conditions, and southern Chile is now. In forested regions, lumbering is likely to be an important industry, and forest products are leading articles of trade. In these same localities, also, mountains near the coast cause heavy precipitation, much of which is in the form of snow. The melting of these snows in summer keeps the streams full, even when the rainfall is least. Mountain streams afford water power, which favors the handling of timber. Among native tribes, forest conditions lead to hunting and fishing as regular pursuits.

The change of climatic conditions with increasing latitude has resulted in significant contrasts in the occupations of the people along the west coast of both American continents. Chile, which extends through more than 35° of latitude, affords a good illustration. In the northern part of this country, there is a coastal desert near the margin of the trade-wind zone. Here conditions have favored the accumulation of guano and nitrate deposits, which have been the basis of important industries and commerce, and the cause of bitter strife between Chile and Peru. South of the desert, the sub-tropical type of climate has led to irrigation and the growth of fruits. Still farther south, where the climate is of the type under consideration, grazing and the raising of cereal crops and vegetables are the chief occupations. In the extreme southern part of the country, the heavy rainfall from the westerly winds supports luxuriant forests, and forest industries and fishing are the chief occupations. Similar contrasts exist along the western coast of North America from California northward, and along the coast of Europe from Spain to Norway. If the marine influence did not penetrate far inland, the densely populated and highly developed countries of western Europe, especially north of latitude 50°, would be far less important than now.

4. CONTINENTAL CLIMATES

Regions affected. The contrast in climate between the continental interiors and the windward coasts of the temperate zone is due to (1) the fact that land absorbs and radiates heat more readily than water, (2) the effect of topography, (3) greater distance from the sea to windward, and (4) cyclonic storms.

The continental climate is not developed in the south temperate zone, except in the southern part of Argentina. North America and Eurasia, on the other hand, have their greatest width in rather high latitudes (Fig. 101), and this favors the full development of continental climates. In North America, there is a sharp transition inland from the marine climate of the western coast to the continental climate of most of the United States and Canada. In Eurasia, the conditions already noted (p. 191) limit the continental type of climate chiefly to the Russian Empire and the interior of China.

Temperatures. The first and most pronounced characteristic of the continental climate is *extremes of temperature* (Fig. 102). The winters are cold, the degree of severity increasing (1) with the latitude, and (2) with increasing distance from the sea to windward. In latitude 45°, in North America, the lowest temperatures are about —30°F. Farther north they are still lower, reaching —60°, or even less, near the northern limit of the zone. A great area in northeastern Asia, far from the ocean to windward, has extremely low temperatures in winter (Fig. 102).

Only in the northern part of the United States does the temperature ever fall to —40°. But, except in the Gulf region, there is no large section east of the Pacific coast where temperatures of 10° to 20° *below freezing* do not occur every year. The summers are hot. July averages of 60° are found beyond the northern margin of the zone, and maximum temperatures of 80° to 90° occur close to the Arctic Circle (Fig. 102). In the southern part of the zone, the summer temperatures are almost tropical.

The annual ranges of temperature are very great, especially for the northern part of the north temperate zone. In northwestern Canada, the difference between the lowest and the highest temperatures of the year has reached 150°, and in northeastern Asia, 180°. The high mountains to windward of northwestern Canada have much the effect of a wide expanse of land on its climate. In the lower latitudes the extremes are not so great. The winters are milder,

ng to the lower latitude, but the summers are not correspondingly armer. Thus in our southern states only small areas ever have emperatures above 100°, and except for the immediate Gulf coast the mean maximum temperatures are under 90°, or no higher than those occasionally recorded near the Arctic Circle.

Cyclonic influence. The second important feature of continental climate is the variability of weather from day to day.

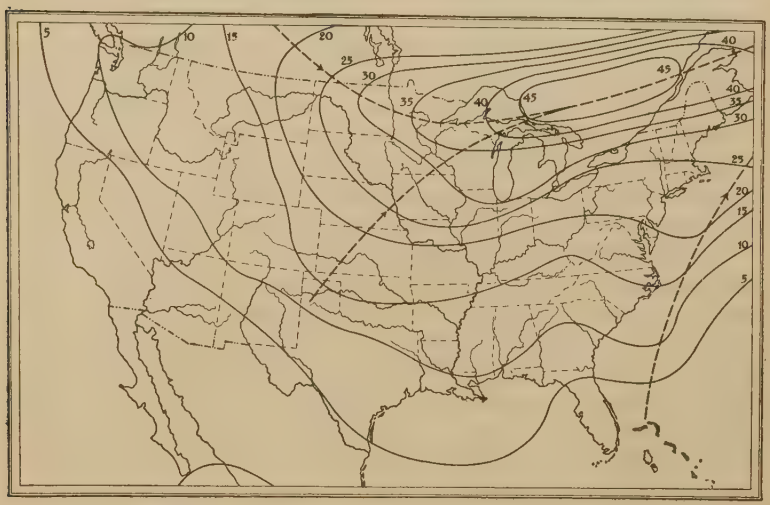

Fig. 105. Chart showing annual storm frequency in the United States. Numbers on lines indicate the average number of storms per year. Broken lines indicate mean storm tracks. (After Dunwoody.)

Cyclones and anticyclones interrupt the prevailing westerly winds frequently (Fig. 105), and within the course of a few days give winds from all points of the compass. Each wind tends to bring its own distinctive weather conditions. Thus, the northerly winds of anticyclones in winter carry freezing temperatures almost to the southern margin of the zone (Figs. 87 and 88). This is illustrated in the Gulf States, where a change from normal mild conditions to a temperature of 20° F. may occur in a single day. On the other hand, southerly winds carry warm air to comparatively high latitudes (Fig. 70), and may produce a summer-like temperature in mid-winter, even as far north as New York and Chicago. Cyclonic storms occur frequently

Fig. 106. Mean annual rainfall in the United States. (After Gannett, from data of U. S. Weather Bureau.)

(Fig. 105); hence there is repeated change from clear, cold, and dry days, to cloudy, warm, and damp days.

Rainfall. A third important feature of the continental climate is its rainfall, which is moderate or scanty (Figs. 69 and 106). In most places it does not exceed 40 inches a year, and most of it comes during the spring and summer months (Figs. 103 and 107). There is a tendency toward a dry season in winter, but, as a rule, some rain falls each month, except in desert or semi-desert regions. The occurrence of the maximum precipitation (Fig. 107) when temperatures are favorable for plant growth is the most important aspect of the rainfall.

These temperature and rainfall conditions are associated with lower humidity (Fig. 44), less cloudiness (Fig. 50), and greater evaporation (Fig. 43) than go with the marine climate. In these respects the climate of continental interiors is more like sub-tropical climate than like the marine climate of the temperate zone; but the continental climate differs from the sub-tropical in its lower average temperature, and in its greater extremes.

The rainfall of this climate is moderate, because most lands affected by it are (1) remote from the ocean, and (2) devoid of important local sources of moisture. The effect of the first point is illustrated by the distribution of the rainfall of Eurasia. The western slopes of the British Islands receive 80 to 100 inches of rain yearly; in Germany and western Russia, the amount is 20 to 30 inches; in eastern Russia and western Siberia, between 15 and 20 inches; while in central and eastern Siberia, large areas have less than 10 inches. In southern Siberia, in the lee of the mountain ranges of central Asia, the rainfall is as little as 5 inches in many localities.

Arid and humid interiors. On the basis of rainfall, two subdivisions of continental climate are recognized, the one *humid* and the other *arid*. The two types merge into each other through a zone of intermediate rainfall (*semi-arid*). Forests are characteristic of the humid climate. From dense forests, where rain is plentiful, there are gradations through less dense forests, to treeless tracts, covered with grass. Most grassy lands mark the transition from the humid to the arid type of continental climate. Toward arid regions the grassy vegetation becomes meager, and finally gives place to desert growths. In a general way, dryness increases with increasing distance from the ocean to windward; but topography and cyclonic storms modify this general relation. Altitude is an important factor

Fig. 107. Map of United States showing the percentage of annual rainfall received in the six warmer months, April to September. (After Gannett. U. S. Geol. Surv.)

in continental climate, especially in the drier tracts, because it increases precipitation. The increase is enough in many places to cause a transition from arid conditions on lowlands, to grassy lands at moderate altitudes, and timber still higher up. As in tropical deserts, this local effect of high elevation plays an important part in the life of the arid regions.

Continental Climates in the United States

The arid portion of the United States lies near the western coast (Fig. 108), because the Sierra Nevada, Klamath, and Cascade mountains stop much moisture which the winds from the Pacific Ocean

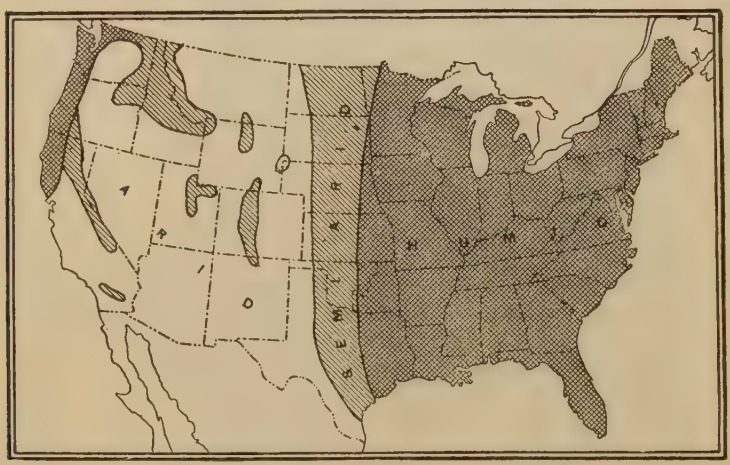

Fig. 108. Map showing arid, semi-arid, and humid regions of the United States. (After Newell.)

would otherwise bring farther inland. These mountain barriers limit the rainfall of about half the country to less than 20 inches a year. The western half of our country, therefore, is affected mainly by the arid and semi-arid types of climate, the drier part lying to the west, and the grassy (prairie or steppe) districts to the east.

The interior of the country, therefore, may be divided into three areas (Fig. 108), according to the amount of rainfall — (1) the *arid*, chiefly between the Sierra Nevada and Cascade mountains on the west and the Rocky Mountains on the east; (2) the *semi-arid*, between the Rocky Mountains and longitude 98° to 100°; and (3) the *humid* tract,

lying farther east. All these regions are much alike in having extremes of heat in summer, and of cold in winter. They also have great changes of temperature and humidity from day to day, as a result of passing cyclones and anticyclones. The difference in the amount of rainfall, however, makes conditions of life very different in the three regions.

(1) *The Arid Region*

The arid region (Fig. 108) includes most of the Cordilleran section of the United States, except the high mountains, on which the rainfall may amount to 30 or 40 inches (Fig. 106). The average annual rainfall is less than 15 inches, and is less than 10 inches over large areas. Hence much of the land is almost desert, sunshine prevails throughout the year (Fig. 50), relative humidity is low, and evaporation high. The nights are usually cool even when the days are hot. The heat of summer (Table VI), though frequently marked by high maxima (Tucson, mean max. June, 100°), is so modified by the low humidity that the sensible temperatures are not very high. So far as the combined effects of temperature, humidity, and sunshine are concerned, the arid district has an agreeable climate.

Table VI

Continental Climate—Arid Type

Temperature

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Year
Logan, Utah	41° 44′	24°	34°	55°	71°	55°	38°	47°
Tucson, Ariz	32° 14′	50°	59°	74°	88°	81°	59°	68°

Rainfall (inches)

	Jan.	Mar.	May	July	Sept.	Nov.	Year.
Logan, Utah	1.1	1.8	2.2	0.4	1.1	1.1	14.1
Tucson, Ariz	0.7	0.6	0.1	1.8	0.8	0.7	9.8

Extremes

	Temperature				*Rainfall*	
	July Mean Max.	Jan. Mean Min.	Abs. Max.	Abs. Min.	Wettest year	Driest year
Logan	86°	21°	100°	−19°	17.3 in.	12.6 in.
Tucson	99°	35°	112°	10°	14.6 in.	5.2 in.

Effects of scanty rainfall. The scanty rainfall (Tucson, Table VI) means scanty vegetation of nearly worthless types, except where high altitudes cause rain enough to support grass or timber. The rapid evaporation of water from the ground leaves the alkaline sub-

stances of the water in the soil, and the slight rainfall is not enough to dissolve and carry them away to rivers and thence to the sea. In some places this gives rise to alkaline soils, which are unfavorable to vegetation, and require elaborate treatment before they become productive. Where not alkaline, desert soils are naturally rich, because elements important for plant food have not been leached out (p. 448). Hence where water can be supplied to desert lands, they are usually highly productive.

The use of the desert depends largely on the availability of water. Where rainfall is enough to support even a meager growth of grasses, the grazing industry, especially the raising of smaller animals like sheep and goats, is an important occupation. Many mountains receive much snow in winter, and this may afford water for irrigation. The total area which can be irrigated, however, is but a small portion of the entire arid district (p. 449). The tillage of soil is therefore not the most wide-spread industry of arid lands.

Mining is an important industry in parts of the arid West, though aridity has little or nothing to do with the development of the ores. In some places, the absence of sufficient water or timber, or both, has been a severe handicap to mining. Desert conditions favored the accumulation of salt deposits, as about Salt Lake, and borax deposits, as in Death Valley, California.

The population of the arid section is necessarily scanty, because there is no natural basis for permanent or extensive settlement in most localities.

(2) *The Semi-Arid Region*

The arid section gives way gradually to a semi-arid region lying east of the Rocky Mountains (Fig. 108), and west of longitude 98° to 100°. Here the yearly rainfall is between 15 and 20 inches (Fig. 106), with a distinct maximum in the spring and summer months (Fig. 107, and North Platte, Table VII). The tract has only one mountain area (the Black Hills), hence there is little increase of precipitation as the result of altitude, and forests are generally absent. The section is typically sunny and dry, with high temperatures in summer (Table VII), and low temperatures in winter. The sensible effects of the extremes, however, are moderated by the dryness of the air. The open character of the country favors free circulation of the atmosphere, and fairly constant winds of moderate to high velocity are more or less typical of most of the region.

Table VII

Continental Climate—Semi-Arid Type

Temperature

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Year
North Platte, Neb.	41° 8′	24°	35°	59°	74°	63°	35°	48°
Abilene, Tex.....	32° 23′	44°	55°	72°	82°	75°	54°	64°

Rainfall (inches)

	Jan.	Mar.	May	July	Sept.	Nov.	Year
North Platte.....	0.4	0.8	2.8	2.6	1.4	0.4	17.9
Abilene.....	0.9	1.3	3.8	2.0	3.2	1.3	24.5

Extremes

	Temperature				*Rainfall*	
	July Mean Max.	Jan. Mean Min.	Abs. Max.	Abs. Min.	Wettest Year	Driest Year
North Platte	86°	10°	107°	−35°	30 in.	11.1 in.
Abilene.....	93°	33°	110°	−6°	35.5 in.	15.7 in.

Effect on life. The semi-arid district is a region of grass land, the rainfall being insufficient for most cultivated crops (Table VII). Grazing has consequently been the most general occupation, and cultivation of the soil has been restricted chiefly to river valleys (p. 495). A supply of water is highly prized, and not infrequently bitter contests have been waged over the question of ownership. Thus the use of the waters of the Arkansas River, which flows from Colorado into Kansas, was the cause of a long legal battle between the two states, because there was not water enough for both.

(3) *The Humid Region*

The semi-arid region merges gradually into the humid region farther east (Fig. 108). The temperatures of the latter (Ottawa, Ill., Table VIII) are similar to those of corresponding latitudes farther west, but cloudiness and humidity are greater, and evaporation less; hence sensible temperatures are higher in hot weather. The rainfall is rarely as low as 20 inches a year, and most of it comes in summer (Fig. 107). The amount of rain necessary for crops without irrigation varies with the latitude. More is needed in Oklahoma than in Dakota, because the higher temperature and lower humidity of the former cause greater evaporation. In the western part of this region, trees appear in the river bottoms; farther east, they become more abundant, and forests are found (or were once) where the rainfall is heavier.

Throughout the humid region, the rainfall is adequate for cultivated crops, and contains some of the greatest agricultural tracts of the temperate zone.

Table VIII

Continental Climate—Humid Type

Temperature

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Year
Ottawa, Ill.....	41° 20′	24°	36°	62°	76°	65°	39°	50°
Chicago,[1] Ill.....	41° 53′	24°	34°	57°	72°	64°	39°	48°
Meridian, Miss...	32° 21′	46°	56°	72°	80°	74°	54°	64°

Rainfall (inches)

	Jan.	Mar.	May	July	Sept.	Nov.	Year
Ottawa.....	2.2	2.9	4.0	4.0	3.6	2.5	36.7
Chicago.....	2.0	2.5	3.5	3.6	3.0	2.6	33.4
Meridian.....	5.0	5.8	4.3	5.3	3.0	3.0	53.4

Extremes

	Temperature				*Rainfall*	
	July Mean Max.	Jan. Mean Min.	Abs. Max.	Abs. Min.	Wettest Year	Driest Year
Ottawa, Ill.....	89°	15°	112°	−26°	55.7 in.	26.9 in.
Meridian, Miss.	90°	37°	104°	−6°	72 in.	44.5 in.

Because of the higher humidity, the high temperatures of summer are more trying here than in the more arid regions to the west. The low temperatures of winter are also harder to bear than are the greater extremes of "dry cold" where the humidity is lower.

Effects on life. The crops raised are determined largely by the climate. Wheat, for example, is raised most in the less rainy regions (Fig. 410), and its seed time and harvest are influenced by climate. In the north, spring wheat is grown, largely because the winters are too rigorous for wheat sown in the autumn. Farther south, where the winter season is shorter and milder, both winter and spring wheat may be grown, the former predominating in many sections. The harvesting of winter wheat begins in the south in June, and the harvesting of spring wheat ends in the north about the first of September. The harder varieties of wheat, rich in gluten and good for macaroni, are grown in the drier sections, while softer varieties, less rich in gluten, but good for flour, are grown where rain is more plentiful (p. 543).

[1] Chicago, 83 miles east of Ottawa, has a climate modified by Lake Michigan, as indicated by the above data.

The best climate for wheat is one with a dry, sunny harvest season, such as that of the Sacramento Valley, in California, and of eastern Washington (p. 193). This ideal climate is not found in much of the humid interior. Wheat is the standard crop only in a north-south belt, some ten degrees in width, just east of the 100th meridian. Even here, the climate is not so good for wheat as that of eastern Washington.

East of the wheat belt, the heavier annual and summer rains are favorable for a variety of crops. Corn is the standard cereal in great areas (Fig. 409), though wheat, oats, and other crops are commonly grown in rotation with it. Most of the corn is grown south of the wheat belt, because corn requires a higher temperature, and for some varieties a longer warm season. With corn, many other cereals, vegetables, and fruits are grown, all requiring more moisture than wheat.

The humid continental region of the United States is the region of greatest development. It has the major part of the population (Fig. 442), it contains most of the chief cities (p. 595), its manufacturing and commercial activities are greatest (p. 573), and its transportation facilities are most extensive (Fig. 440). All these lines of development are connected more or less intimately with the abundant yield from the soil, a result in large part of favorable climatic conditions.

Climate of Lee Coasts in the Higher Latitudes

Temperatures. The eastern coasts of the northern continents, especially in latitudes above 40°, lie in the lee of broad land areas (Fig. 101). In the southern hemisphere, only South America extends south of latitude 40° (Fig. 100), and above the 40th parallel that continent is nowhere more than 600 miles wide. Hence the leeward coast type of climate, in high latitudes, is confined chiefly to the north temperate zone. This type of climate is similar to the humid continental type, with extremes of heat, cold, and drought reduced. It is very unlike the climate of windward (western) coasts in the same latitudes. The westerly winds carry the continental influence to the eastern coasts, and, in fact, to islands off-shore. Thus St. Johns, Newfoundland, more than 300 miles from the mainland, Lat. 47° 34′, has a mean annual temperature of 41°, with a January mean of 24° and a July mean of 60° (mean maxima of 84° and mean minima of 8°). These temperatures are quite unlike those of Astoria (Table IV, p. 192), in nearly the same latitude.

The climate of the Japanese Islands also shows the effect of the Asiatic land mass to the west. Thus Nagasaki, in about the latitude of San Diego and Charleston (Table III, p. 189), has a mean annual temperature of 60°, a July average of 80°, and a January average as low as 41°. The British Isles, lying in a corresponding position on the windward side of the Eurasian continent, but in a much higher latitude, do not show so great seasonal differences. (Plymouth, Eng., Lat. 50°, mean ann. 51.2°; Jan. mean 42.4°, July mean 61.8°.) The climate of eastern coasts in high latitudes, therefore, is essentially continental.

The larger area of Asia makes its effect on the lee coast somewhat greater than that of North America. Thus Vladivostok is, on the average, 18° colder in January than Portsmouth, N. H., in about the same latitude (43° 5′ N.). This difference is important to the marine commerce of the United States, for none of our important harbors are hampered much by ice. If the eastern coast of North America were as cold as that of Asia in corresponding latitudes, it would be blocked by ice for weeks each year, as far south as New York City. (Niuchwang, Lat. 40° 53′, Jan. mean 15°; New York, Lat. 40° 43′, Jan. mean 30°.) The Amur River, in east Asia, is ice-blocked about seven months a year; the St. Lawrence, but little farther north, is closed about five months.

Great changes of temperature in the United States are favored by the paths of cyclonic storms (Fig. 105). As the latter cross the continent, they tend to converge toward the area lying between the 40th parallel and the St. Lawrence Valley. Hence that coastal section has a most variable climate. Nevertheless the tempering influence of the sea is seen by comparing the temperatures of New Bedford (Table IX) with those of Ottawa (Table VIII), in a similar latitude.

As a result of the contrast between windward and leeward coasts, northwestern Europe and northeastern North America, in corresponding latitudes, are radically unlike. The contrast between Labrador and the British Isles is striking. Labrador—cold, bleak, and undeveloped—has a continental climate. The British Isles—mild, moist, and highly developed—show the full benefit of the moderating influence of the sea. The continental influence is felt along lee coasts, especially in winter, in comparatively low latitudes. Tampa, Florida, Lat. 27° 57′, for example, has minima of 32° or lower almost every year. This condition affects agriculture greatly, for sugar cane, rice, and

many tropical or semi-tropical fruits grown in the Gulf states are injured severely by a freezing temperature.

In the lower latitudes, the contrast between windward and leeward coasts is most marked in summer; in higher latitudes, it is greatest in winter (Why?). This may be seen by comparing the stations in Table IX with those in similar latitudes on the Pacific coast (p. 187).

Table IX

Continental Climate—East Coast

Temperature

	Lat.	Jan.	Mar.	May	July	Sept.	Nov.	Year
New Bedford, Mass.	41° 39′	28°	34°	55°	69°	62°	41°	48°
Charleston, S. C.	32° 47′	50°	58°	73°	82°	76°	58°	66°

Rainfall (inches)

	Jan.	Mar.	May	July	Sept.	Nov.	Year
New Bedford	4.4	5.1	3.9	3.4	3.4	4.4	47.9
Charleston	3.6	3.8	3.6	7.4	5.5	3.0	53.4

Extremes

	Temperature				*Rainfall*	
	July Mean Max.	Jan. Mean Min.	Abs. Max.	Abs. Min.	Wettest Year	Driest Year
New Bedford	77°	20°	94°	−11°	62.6 in.	43.6 in.
Charleston	88°	43°	104°	7°	78.4 in.	29.7 in.

The influence of the ocean is felt along the east coasts chiefly in two ways. First, the summer temperatures are somewhat cooler (Fig. 102), particularly above the 45th parallel, because of frequent winds from the oceans. This cooling influence is felt less in the United States than in Canada, especially in Labrador. Hoffenthal, in southern Labrador, has a July mean of only 49.8°, as compared with 63.5° at Norway House, at the northern end of Lake Winnipeg. The latter is near the great Canadian wheat district. In Labrador none of the cereals will ripen. The meager population therefore finds its chief support in fishing, hunting, and trapping. Fishing especially is important during the summer, and when the catch is small, the people suffer greatly from want during the long, cold winter.

Shore towns in nearly all latitudes feel the beneficial effects of the sea-breeze (p. 114), and many important sea-shore resorts from New Jersey northward are the result.

Rainfall. A second effect of the ocean is on the rainfall. Both North America and Asia (Fig. 69) show an increase in the amount of rainfall as the lee coast is approached. Under varying local conditions, a slight maximum may appear in almost any season. Summer maxima are most common in middle latitudes, but winter maxima are common in high latitudes. A belt where the rainfall exceeds 40 inches lies parallel to the eastern coast of the United States throughout its entire length. This is due to the in-draught of air from the ocean during the movement of cyclonic storms. Indeed, the entire eastern half of the United States depends for its plentiful rain on cyclones (p. 132).

The same factors which increase the rainfall along our eastern coast increase also humidity (Fig. 44), cloudiness (Fig. 50), and fog, and so lower the rate of evaporation (Fig. 43). Places exposed freely to the sea (like Newfoundland) have conditions of humidity, cloudiness, and fog similar to those of marine climates on western coasts. As a result, the sensible temperatures of summer are high and those of winter low.

In contrast with the eastern coast of North America, much of the eastern coast of Asia has such a distinct summer maximum of rainfall that its climate might be called a *temperate monsoon climate*. In the winter time, on the contrary, the out-flowing wind from the continental interior gives clear, cold, and dry conditions over most of the coast. The winter cold is greater than in corresponding latitudes in eastern United States, but varies considerably in degree. Places on the coast opposite large valleys leading from the interior are colder in winter than places lying much farther north, but shielded by mountains. Thus Nikolayevsk, Lat. 53° 8′, near the mouth of the Amur River, has a January mean of —10.1°; and Ayen, Lat. 56° 28′, protected by mountains to the west, has a January mean of —4.7°.

Effects on life. The climate of lee coasts in general is so like that of humid continental interiors that the conditions of life in the two situations are much the same. The chief difference is that temperature changes of a given amount are felt more near the coast than in the interior, because humidity is higher. In the United States, the ill effects of variable weather and climate are greatest in the coastal sections of the northeastern states. This is shown in the greater prevalence of colds and affections of the respiratory organs (especially catarrh).

The humid parts of the temperate zone are the great cereal districts of the world. They bear the same relation to the cultivation of cereals that the semi-arid steppe lands, with their grassy vegetation, bear to the live stock industry of the world. Thus the great wheat regions lie mainly between the 40th and 55th parallels. Rye, closely related to wheat in its uses and conditions of growth, replaces wheat in many localities where the soils are too poor for the latter. Of the other great cereal crops in this belt, oats and barley are to the north, and corn to the south. Hence, through the heart of the temperate zone is found the home of all the cereals, save rice, which serve as food for man. This arrangement of important crops influences both the distribution of population and the movement of commerce. The populous part of the temperate zone corresponds closely to the cereal belt. Much of the commerce of the world now moves along east and west routes in these same latitudes. No other country is situated so well as the United States with respect to cereal-growing lands.

The whole humid section in the interior of this country is in danger of sudden frost in late spring and early autumn (Fig. 109), and in either case wide-spread damage may result. Its southwestern part is exposed to hot winds from the south, which, in exceptional cases, wither and kill crops. Droughts are common, though less frequent and less wide-spread than in monsoon countries. Almost every year some part of the humid portion of the United States suffers from too little rain; but severe drought rarely affects a great area, or the same area frequently. In monsoon countries like India, on the other hand, a large area suffers from drought at the same time, and the same area may suffer for a period of years. Tropical and sub-tropical Australia also has frequent and long-continued droughts which affect large areas. Hence in spite of its extremes of climate, central and eastern United States is a highly prosperous agricultural region, largely because of its reliable rainfall.

The northern limit of the north temperate zone is so far north that the summers of interior lands near it are too short and too cold for cereals. In the most favorable parts of continental interiors, not even the hardiest cereals can be produced much beyond the 60th parallel (Fig. 101). Dense forests practically disappear before the northern margin of the zone is reached, being replaced by the scattered trees and scanty vegetation which mark the beginning of the frozen polar wastes. Both Canada and Russia have large

areas of nearly worthless, almost uninhabited, northern territory (p. 507). The United States, on the other hand, is neither too far north nor too near the equator. Climatically, it has the best position of any large country.

5. MOUNTAIN CLIMATES

Temperature. Even moderate altitudes so affect temperature as to determine what crops may be cultivated. For example, in the

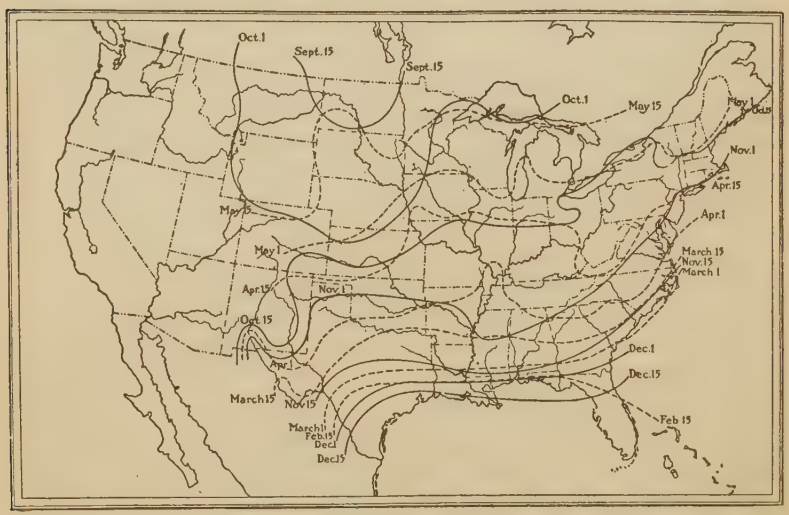

Fig. 109. Map of United States showing average dates of last killing frost in spring (broken lines) and first killing frost in autumn (solid lines). (After U. S. Weather Bureau.)

plateau sections of Pennsylvania, in Lat. 40° to 42°, corn cannot be depended on to ripen at an altitude of 2,000 feet. In some of the drier, hence warmer (in summer) and sunnier, parts of the arid West, corn, under irrigation, will ripen at much higher altitudes (4,000 feet about Great Salt Lake). In general, the upper limit for even the hardiest crops does not exceed 6,000 feet, even in the lower latitudes of the temperate zone. In contrast, corn is grown in Bolivia at an altitude of 10,000 feet, and wheat even higher. The *timber-line* (upper limit of timber) in the United States ranges from an altitude

of about 11,000 feet at the south, to 7,000 or 8,000 at the north, and the level at which snow lies most of the time is not far above these limits. Hence, so far as agriculture is concerned, the higher lands of the temperate zone are of little use.

Precipitation. The effect of altitude on rainfall is the same in the temperate zone as elsewhere. It increases the amount of precipitation, and tends in many cases toward a maximum in winter. In most places, the increased precipitation at higher altitudes results in heavy snowfall (Fig. 110) in winter. Thus Baltimore, altitude 104

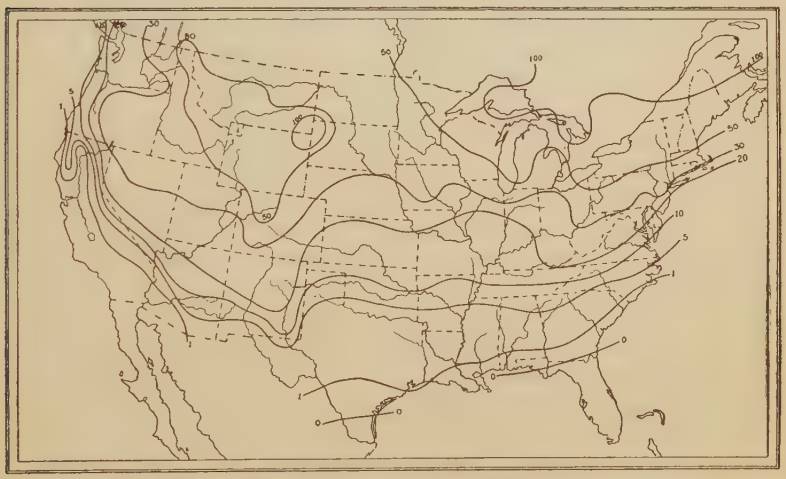

Fig. 110. Mean annual snowfall in inches, for United States. The snowfall on the Sierra Nevada and Rocky mountains is much greater than shown on this chart. (After Henry.)

feet, has an average of 23.8 inches of snow annually, while Grantsville, Md., altitude 3,400 feet, has 71.2 inches. Summit, the top of the pass crossed by the Central Pacific railroad, east of Sacramento, Cal., has over 400 inches of snow in a year, and nearly 300 inches have been recorded in a single month. Sacramento, on low land to the west, has only a trace of snow each year.

Winter snowfall (Fig. 110) is an important factor in the flow of many rivers. Water from rapidly melting snow may cause winter and spring floods in some cases, and in other cases the gradual melting of snow aids in (1) the development of water power,

(2) the maintenance of a sufficient depth of water for navigation, and (3) irrigation. Heavy winter snows and snowslides offer serious problems to railroad lines which run at high levels, and at the bases of mountains. Snowslides are one of the things to be feared about mines in mountains, and they are in some cases destructive to mountain villages.

Mountain conditions of temperature and rainfall favor forests, and make many mountains the sites of lumbering (p. 480). Forest trees thrive far above the altitudes which limit crops. Different species of trees prevail at different altitudes, and with different amounts of rainfall. Thus in Pennsylvania, a large variety of forest trees is found, with a resulting wealth of forest resources, in a relatively small area. Even in many arid regions, lands 5,000 to 6,000 feet high have rain enough to support forests of commercial value.

Many mountains serve as health resorts as well as pleasure resorts (p. 482). In most cases the mountain health resort is related to the treatment of diseases of the lungs, especially tuberculosis. Mountain climate is not a cure for tuberculosis; but the conditions afforded by the climate of the mountains may aid in checking the disease, or may even enable the organs affected to throw it off. The favorable conditions are (1) the pure, dry air characteristic of the higher altitudes, and (2) the decreased density of the atmosphere, which stimulates the lungs to greater activity. In the arid parts of western United States especially, these conditions are associated with bright, sunny weather (Fig. 50), which favors out-of-door life.

Questions

1. Suggest various ways in which temperatures and changes of temperature during a year affect people and their occupations.

2. Explain the absence of summer rainfall in sub-tropical climates, even with winds from the ocean.

3. Account for the daily morning fogs of the coast of southern California in summer.

4. Explain fully the differences of climate between the coastal and interior stations in California (Tables I and II). Suggest probable effects of these differences on man and his occupations.

5. Discuss the influence of the Gulf of Mexico on the climate in southeastern United States during summer. During winter.

6. Give the reasons for the differences in climate between the stations in Table IV. State some effects of these contrasts on the life of the region.

7. How would you expect the distribution of population in Chile to be affected by climate (p. 194)?

8. Why is the Pacific Ocean not the chief source of moisture for the United States?

9. Explain the differences in climatic conditions along the 41st parallel in the United States. Along the 32d parallel.

10. What would be the commercial effects, if the ports as far south as New York were ice-bound for two months in winter?

11. Why are there few summer resorts on the Atlantic coast south of Delaware Bay?

12. What would be the probable effects on the climate of the United States if a mountain range stood along the Canadian boundary line?

13. Explain the increase in rainfall from San Diego northward to Astoria.

14. Why is the limit of cereals and of permanent habitations nearer the equator in the areas shown by Fig. 100 than in the areas shown by Fig. 101?

15. How does the course of the isotherm of 50° in Fig. 100 differ from that of the same isotherm in Fig. 101? Why?

16. Suggest reasons, based on Figs. 100 and 104, why there is little commerce between lands of the South Temperate Zone.

17. Why should the northeast coast of the United States have more rainfall in winter than in summer? See Figs. 103 and 107.

18. Why do the lines showing average dates of frost (Fig. 109) turn northward over Lake Erie and along the south Atlantic coast?

19. Why is the snowfall in the Mississippi Valley heavier than that in the corresponding latitudes on the Atlantic coast?

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CHAPTER XI

CLIMATE OF POLAR REGIONS

General Considerations

Extent of polar regions. The limits of the polar regions are commonly placed at the Arctic and Antarctic circles; but they are sometimes regarded as being limited equatorward by the isotherm of 50° for the warmest month, an isotherm which marks the approximate limit of the growth of trees and cereals (Fig. 111). This isotherm lies south of the Arctic Circle in most of North America and Asia, but north of it along windward coasts, as in Alaska and Norway. In this discussion, the latitude division is used for the sake of simplicity. Such a division gives the polar regions an area about one-twelfth that of the earth.

Land and water areas. The distribution of land and water in the polar regions of the northern hemisphere is nearly the reverse of that in the southern hemisphere. All the continents of the former extend north of the Arctic Circle (Fig. 111), and to the continental lands must be added part of Greenland, and various smaller islands. The ratio of land to water is about 2 to 3. The total extent of land is small, compared with that of other zones, but a wrong notion of its extent is common, because of the use of the Mercator map (p. 25), which exaggerates areas in high latitudes. The only large land area in the south polar region is Antarctica, most of which is covered with snow and ice (p. 218).

General features of polar climate. All polar regions are alike in having the sun above the horizon for more than twenty-four consecutive hours, and below the horizon for a similar period, once each year. Near the equatorward margins of these zones, the longest period of continuous sun is but a few days (of 24 hours each); but the time during which the sun does not set increases poleward until, at the poles, the day (period of continuous light) is six months long (p. 20). During the period of continuous light, insolation is greater in polar regions than in low latitudes (p. 57), but the temperature of the air

is not raised accordingly, because (1) the sun's rays are very oblique (Fig. 35), and (2) much of the heat which reaches the surface melts ice and snow, and is not effective in warming the air. The result is a

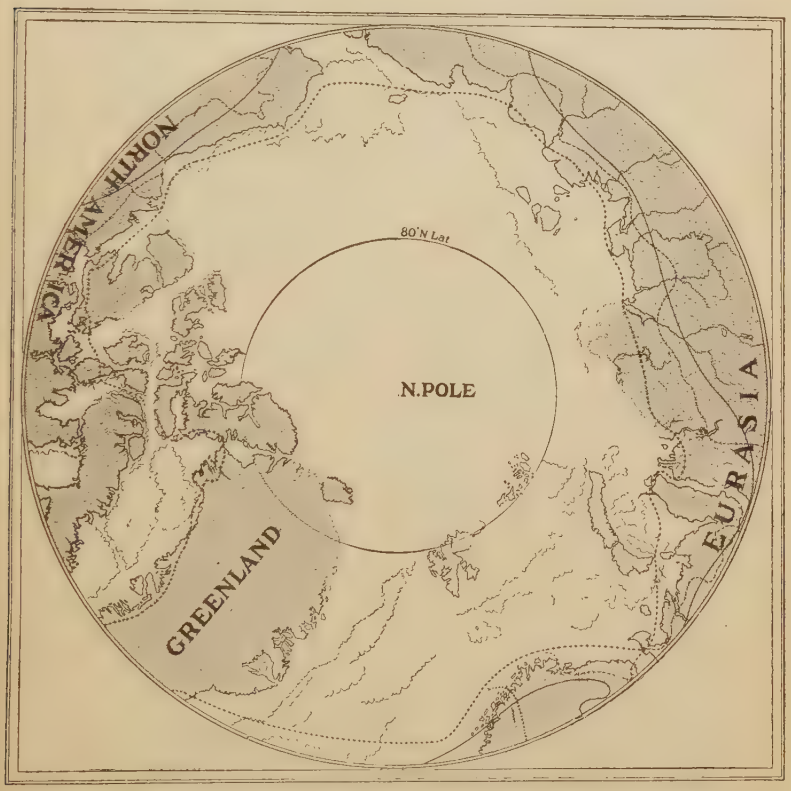

Fig. 111. Map of North Polar Zone, showing land and water areas. Poleward limit of growth of cereals ..... . Poleward limit of growth of forest trees -----. Poleward limit of permanent habitations + + + + +. Isotherm of 50° for warmest month ———.

low temperature for the year, and, except for lands free from snow and ice, a low temperature at all times of the year (Fig. 112).

Our knowledge of the climate of polar regions is rather fragmentary. The known data are from scattered localities, and are mainly the records of observations of different exploring expeditions. More

data are available for the north polar region than for the south. Conditions near the margin of the former are known fairly well, but in the higher latitudes, observations covering long periods of time have not been made.

Temperature. The winters are always cold and, as noted, the average temperatures for the year are always low (Fig. 40). Many of the recorded temperatures of January in the Arctic region range from —40° to —60°. The summers are cool, or even cold. The warmest month has an average temperature of 32° or more in many places, and the maximum summer temperatures close to the margin of the zone are locally as high as 80°, or even 90° (Fig. 112). Such temperatures occur only where there are large areas of land free from snow and ice. Most of the Antarctic region has a summer temperature below the freezing point even for the warmest month, so far as present records show.

The annual range of temperature in the Arctic region is greater than that in the Antarctic, because more land in the former is not covered by snow and ice in summer. In Eurasia, for example, the great area of land near the Arctic Circle, free from snow and ice in summer, becomes warm, but the winter temperatures are the lowest known. Verhoyansk, in Siberia, just within the Arctic Circle (Lat. 67° 6′), has a July mean of +60° and a January mean of —60°. In contrast with this continental locality, Hammerfest (Lat. 70° 40′), on the coast of Norway, and the most northerly town in Europe, has a January mean of 23°, and a July mean of 53°. The latter station shows the full effect of the ocean on the temperature of windward coasts in high latitudes. At Hammerfest, the sun does not set from the middle of May to the end of July.

Humidity and precipitation. The low temperatures affect the other elements of climate. They mean little evaporation, and hence little moisture in the air; but the relative humidity varies from extremely low, especially far from the sea to windward, to relatively high, particularly on windward coasts. The precipitation is light, probably averaging less than 15 inches a year except on windward coasts.

The Shackleton expedition to Antarctica found, from recording instruments left by a preceding expedition (Capt. Scott, the "Discovery"), that the average precipitation for six years had been the equivalent of 7 to 8 inches of rain. Most of the precipitation in polar regions is in the form of snow, and is frequently accompanied by violent winds. Rain is said to fall in most parts of the north

polar region during the warmer months. In the south polar region, on the contrary, the Shackleton expedition found all precipitation during 13 months to be in the form of snow.

The great fields of snow and ice in the polar regions are not due to heavy snow-fall, but to the preservation of most of that which

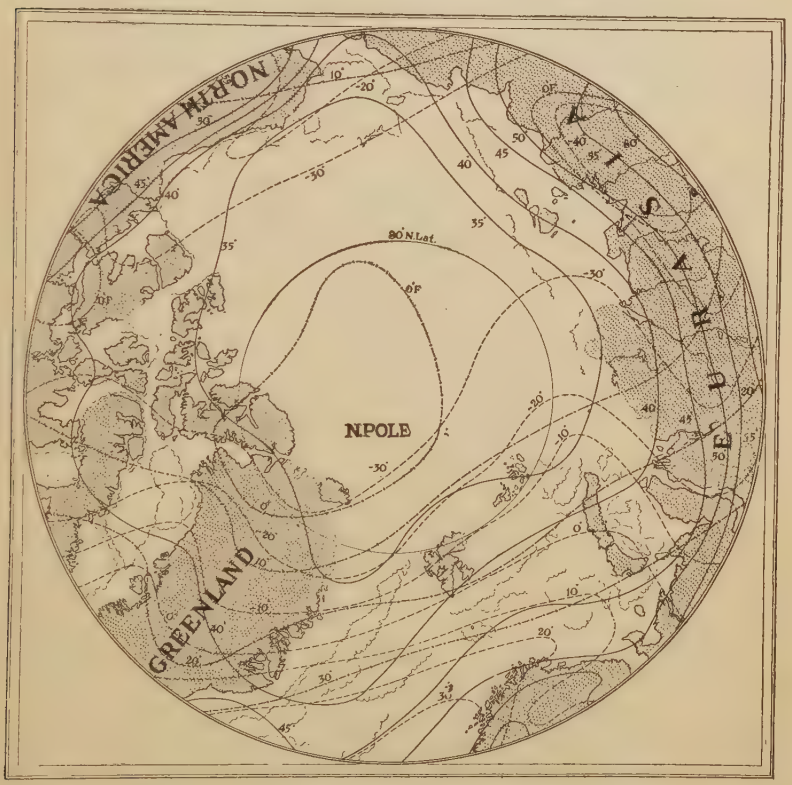

Fig. 112. Map of North Polar Zone, showing mean annual isotherms (-·-·-·-), isotherms for January (-----), and for July (———).

falls. It melts and evaporates little. Instead of being made up of distinct flakes, it is usually in the form of tiny ice spicules, which readily become compact, and make a hard, solid mass almost like ice. It is said that this difference in the character of the snow explains the ease with which the Eskimo makes his snow hut.

The small amount of moisture in the air suggests little cloudiness. Few records on this point are available, but in summer, fogs about the ice-covered lands and seas are common, and are a great hindrance to navigators. Interiors are probably less foggy, and the winters are likely to be clear (Why?).

The northern and southern polar regions are so unlike, with respect to the distribution of land and water, that they may be considered separately, so far as further details of climate and their results are concerned.

The Antarctic Region

The Antarctic region is essentially one of ice-covered water and ice-covered land. South America, which extends farther south than Africa and Australia (Fig. 100), lacks more than 700 miles of reaching the polar circle. The known land within the Antarctic Circle consists of scattered areas such as Graham Land, Coats Land, and South Victoria Land, discovered by various expeditions. It is believed by many that these scattered land areas are parts of the border of an Antarctic continent. Most of the region lies under a cover of snow and ice of great thickness, which meets the sea in many places, with no sign of land beneath it. This "Great Ice Barrier," as it is called, is a cliff of ice 30 to 300 or more feet in height, extending for a known distance of hundreds of miles. Beyond it, the elevation of the surface increases toward the interior to heights of several thousand feet. The major part of the Antarctic region may be described as an ice plateau, though high mountains nearly free from ice project through it in places.

Summer temperature. The isotherm of 50° for the warmest month crosses southern South America (Fig. 100). If the south polar region were limited by this isotherm, it would include everything south of the 55th parallel. The great expanses of ice and ice-water do not allow the temperature of this zone to rise much above 32°, even in summer. During the summer, fog and cloud are reported as being so frequent that much insolation is cut off. Fogs and clouds are therefore important factors in keeping the summer temperatures low.

Winter temperature. The mid-winter (July) temperatures of the lower latitudes of this zone are about —15° to —20°, so far as recorded. The temperatures of higher latitudes are probably much lower. The real character of the winter may perhaps be shown better

by the fact that the Shackleton expedition recorded a winter minimum of —57°, and the report of the voyage of the "Discovery" shows a minimum of —67°.

The seasons between winter and summer are very short. The one shows a rapid rise from the low temperatures of winter, and the other a rapid drop from the temperatures of summer.

Effects on life. The effect of these temperatures on life is marked. The Antarctic region is devoid of most kinds of vegetation familiar to us. Some mosses and lichens are found on such lands as are free from ice for a part of the year, but no form of vegetation useful to man is known.

The animal life is mainly marine, whales and seals being characteristic species. The waters abound in lower forms of life, such as molluscs and still simpler types. The only varieties of animal life on the land are a few birds and insects. For the former, the Cape Adare region (Victoria Land, south of New Zealand) is perhaps the chief locality. Here, in latitude 71° S., the great rookeries of penguins constitute one of the most remarkable assemblages of bird life to be found anywhere in the world. In addition to the penguin, the albatross, gull, and some other varieties of sea-coast birds are found. From the standpoint of life in general, however, the Antarctic lands are as close an approach as there is to an absolute desert.

The Arctic Regions

Parts of Alaska, Canada, Scandinavia, Russia, and Siberia, and a number of large islands are in the north polar zone (Fig. 111). The lands here are in the lower latitudes of the zone, not in the higher, as in the southern hemisphere.

A part of the Arctic region is like most of the Antarctic in being covered with snow and ice all the time, but a larger part is not so covered. In the higher latitudes of the zone, the Arctic Ocean is covered with ice most of the year, though it is more or less broken in the summer. In the lower latitudes of the zone, much of the ocean is free from ice all or part of the time. In addition to the ice on the ocean, snow and ice cover all but the fringe of Greenland, and the larger part of many other islands. In Greenland, the snow and the ice developed from it have reached such a depth as to conceal all inequalities of surface beneath (p. 385).

The Arctic portions of the continents are not covered by ice

and snow during the summer, and their climate is in sharp contrast (How?) with that of regions which are so covered. There is also a contrast between the interior lands which are snow-free during the summer, and windward coasts, such as western Alaska and northwestern Norway, which are affected by the moderating influence of winds from the oceans.

Temperature. The temperatures of the Arctic zone vary widely. The lowest yearly temperatures are found where there is a permanent covering of ice. The interior of the ice-cap of Greenland is supposed to have an annual mean close to zero, and an average below 32° for the warmest month of the year. Its temperatures are probably similar to those close to the pole.

The winter conditions in Arctic regions are better known than are those in the Antarctic, because more expeditions have gone north. Such observations as are recorded indicate a January mean of about —40° for northern Greenland, giving it an average annual range of about 70°. The continental interior of Siberia is even colder than Greenland in winter (Fig. 112). The region about Verhoyansk (p. 216) has the lowest average mid-winter temperatures recorded (—50° to —60°), and is known as the "cold pole of the earth." In summer, however, this same region, being without snow or ice, becomes very much warmer than Greenland. The annual range of temperature in Siberia (120°) is, therefore, greater than that in Greenland, while the mean temperature for the year is about the same.

The Arctic islands near North America have a temperature similar to that of Greenland. Northwestern Canada and Alaska, even back from the coast, are somewhat warmer. At Ft. Yukon, Alaska, Lat. 66° 34′, the average for the winter months is about —24°, and for summer months, 57°.

Arctic lands free from snow in summer have great extremes of temperature, beyond the average annual range. The average minima of winter are commonly as low as —70°, and Verhoyansk has reported —94° F., the lowest natural temperature ever recorded. Summer maxima of 60° to 80° are almost typical of the margin of the zone, and average maxima of 60° are not uncommon as far north as latitude 80°. Temperatures of 90° or more are frequently reported from Alaska and Siberia. An extreme range of 150° for the year is common, and the highest summer and lowest winter temperatures recorded are more than 180° apart.

The extreme and long-continued cold of winter is sufficient to

freeze the water in the ground to the depth of scores of feet. The high temperatures of summer suffice only to melt the ice in the top part of the soil. The rapidity with which the Arctic summer comes on, and the brief period of warmth, are indicated by conditions in the interior of Canada near the margin of the zone. Both April and October have mean temperatures ranging from 10° to 15° below the freezing point. The May and September mean temperatures are below 40°, a figure which implies freezing temperatures every night. June, July, and August are warm, with mean temperatures above 50° (near 60° for July). In higher latitudes the monthly means are lower, and the warm season is correspondingly shorter, until there is practically no summer at all.

Plant life. The relatively high temperatures which prevail on ice-free land in summer permit the growth of many kinds of plants. The only Arctic lands without green plants are those permanently covered with ice and snow. As compared with the temperate zone, however, the amount and variety of vegetation are meager.

The southern margins of polar lands support stunted trees of the hardier types, such as larches, pines, birches, and willows (Fig. 111). The average northern limit of these trees is near the 70th parallel in Siberia and northwestern Canada, and their extreme limit about latitude 72°, along some of the sheltered river bottoms in north central Siberia. Dwarf willows and birches (hardly trees) are said to occur 8° or 10° farther north. The limiting factors appear to be wind and evaporation, rather than the low temperatures of winter or the short growing season.

Many varieties of herbaceous plants thrive. Their character and their occurrence are related closely in many cases to topography. On level areas, the soil becomes a sea of mud as it thaws out during the summer. Mosses, lichens, and other low types of plants, are most abundant in the Arctic tundra—desolate, monotonous, and almost worthless.

Where more favorable conditions exist, as in the dry places in the tundra, or on southerly slopes where there are both drainage of the soil and greater insolation, there are large numbers of flowering plants, some of which produce berries. On the west coast of Greenland, poppies are found north at least to latitude 78°. The plants of these high latitudes are for the most part rapid growers, as the short growing season would let no other plants mature. They have short roots, for all but the upper surface of the soil is frozen.

The temperatures of air and soil virtually exclude crops from the polar region. There are only a few favored localities where the hardier types of cereals may be grown (Fig. 111). Thus in northern Norway, under the influence of the sea, some crops, notably barley, are grown within the Arctic Circle. Small areas in favored situations in Alaska and Siberia permit the growth of the hardiest crops, but in most of the Arctic region agriculture is out of the question. The ice-cold waters of the Arctic regions abound in sea-weeds.

Animal life. Animal life, as well as plant life, is more abundant in the Arctic regions than in the Antarctic. This follows from the greater extent of land, the more favorable temperatures of summer, and the greater amount of vegetation. Sea life is more abundant than land life. The larger sea animals are similar to those of the Antarctic, and include species of whales, seals, and walruses. All these types bear an important relation not only to the life of the inhabitants of the Arctic region, but also to certain industries carried on from places in lower latitudes. Thus, sealing and whale fishing are carried on close to the Arctic Circle, and even within it. The Arctic seas also teem with smaller forms of life. Thus molluscs and small crustaceans abound on the coast of north Greenland, at least as far north as latitude 78°.

Among land species, birds are prominent in the summer. The little auk, dovekies, guillemots, and (locally) the eider duck abound. Among land mammals, the reindeer, fox, hare, polar bear, and musk ox may be mentioned.

The effect on population. The Arctic region, unlike the Antarctic, is inhabited by human beings (Fig. 111). The population, however, is scanty, scattered, and, on the whole, not highly civilized. Along the southern margin of the zone, there are many small groups of people. Farther north, the groups are fewer and smaller, and more confined to coasts. The most northerly permanent settlements are on the west coast of Greenland, the northernmost, Etah, being above the 78th parallel.

For all inhabitants of polar regions, life is a constant struggle. This is in great contrast with the situation in the tropics. In the latter region, the monotonous heat throughout the year means a great bounty from nature, unfailing ease of existence, and consequent lack of incentive to work and progress. The cold of the polar regions means poverty of resources, a constant fight for food and clothing, and consequent inability to progress. In the temperate zone, winter

imposes difficulties somewhat like those encountered in the north, but winter alternates with summer, the season of plenty.

The natives of polar regions depend on animal life. Edible plants are absent, except in the lower latitudes of the zone, and for a short time each year. Land animals, like the reindeer, are comparatively scarce on account of the meager vegetation. Hence the people depend in large part on marine life, and most of them live along the coasts.

Food is furnished by the seal, the walrus, and fish, supplemented by the reindeer, the hare, the bear, and birds. Most of this food can be obtained only during the time of light, which is therefore the hunting season. Food for winter is preserved easily because of the cold. As the latitude increases, the number of days when there is no light also increases; hence, the amount of provision which has to be made against the dark season is greater, and the number of days favorable for hunting is correspondingly less. These factors, as well as climate, tend to limit the settlements to the lower latitudes. The dependence of the people on animal life makes them hunters and fishers. The hunters are usually nomadic, going about in search of game during the summer, but having fixed habitations for winter. The natives who live chiefly by fishing are likely to have permanent settlements, especially if the supply of fish is abundant.

The principal food of the Eskimo is meat, in contrast with that of the tropical native, who lives chiefly on fruit and vegetables. The two types of diet correspond, in a way, to the needs of man in cold and hot countries. The meat produces more fat and more heat. Since fuel and means of cooking are meager, much meat is eaten raw. If cooked at all, it is in the most primitive way. In north Greenland, the tiny fire—a little oil with a wisp of grass or moss for a wick — is used chiefly for melting snow and ice for drinking water.

The dependence of the Eskimo on animal life is shown again in the materials which he uses for his clothing and for his tents. Most of his clothing is of fur. Plant fibers which could be woven or braided together are unknown. The fashioning of garments from furs and skins is comparatively simple. The materials used in making dwellings depend on local circumstances. Where forests are accessible, as along the margin of the zone, or where driftwood can be had from the ocean, as along some coasts, wood is used. Elsewhere, the winter habitation is usually of stone or snow, particularly in the case of hunting tribes. During the hunting season, the hunters live in

tents of skins. In the winter, they settle down in communities, living in stone or snow huts.

The conditions of the Arctic regions exert a considerable influence over practically all details of the life of the people. In summer, travel over large areas of the tundra is almost impossible on account of the mud. In winter, on the contrary, when the ground is frozen and covered with snow, travel by sledge is easy. Weapons and utensils may be made from wood, if it is available; more commonly they are made from bone and hides. The use of these animal products is the characteristic feature of the arts and crafts of the Eskimos. Perhaps in no other thing is their skill shown better than in the manufacture of their kayaks (boats), where the only materials to be had are bone, pieces of driftwood, and hides. Out of these they fashion a craft wonderfully adapted to the uses to which it is put.

Looked at with reference to their surroundings, the Eskimos hardly can be regarded as backward. Probably they make better use of the things at their command than more highly civilized men could, but Arctic climate is too great a handicap to allow them to progress far.

Questions

1. Why is rainfall relatively unimportant in affecting the distribution of people in the polar regions?

2. If the entrance from the Pacific to the Arctic Ocean were widened greatly, what would be the probable effect on the climate of polar North America?

3. Suggest reasons why the Antarctic has been less well explored than the Arctic regions.

4. Do the reasons given in answer to the preceding question help to explain the absence of plants and land animals from the Antarctic land areas?

5. Why do trees grow in higher latitudes in Asia than in North America (Fig. 111)?

6. What factors determine the courses of the isotherms for January in Fig. 112? How?

7. Why are the courses of the isotherms for July different from those for January in Fig. 112?

8. How are the soil conditions of Arctic regions harmful to crops?

9. Why is there an ice-cap over central Greenland and not over lands in the same latitude in northern Asia?

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CHAPTER XII

THE OCEANS

General Considerations

Importance of the oceans. The oceans are of great importance to the rest of the earth in many ways, some of which have been pointed out. Thus the distribution of temperatures, humidity, rainfall, and cloudiness are related closely to the oceans. Waves and currents are constantly wearing away the land in some places and building new land elsewhere. On the whole, destruction exceeds building, so far as land is concerned; consequently, the ocean tends to extend its area at the expense of the land (p. 522).

The ocean is an important source of food, and furnishes large amounts of other useful materials. Thousands of people are employed in getting commercial products from the ocean. Other thousands are engaged in the carrying trade over the oceans. Formerly the oceans were barriers to travel and communication, but swift steamships and cable lines (Fig. 113) now make communication between the continents easy. Nine-tenths of our foreign trade is carried by vessels (Figs. 114 and 115), most of which hail from other countries. Enormous quantities of goods are shipped annually to the United States from all the leading countries of the world and from the United States to these countries (Figs. 116 and 117), over the ocean highway. The voyage across the Atlantic formerly took as many weeks as it now takes days, while the happenings of this morning in Europe may be printed in the evening papers of Buenos Aires.

The ocean basins. The oceans lie in the great depressions in the surface of the lithosphere (p. 33). Fig. 118 suggests the real shape of an ocean basin, which is, in general, convex upward. The surface of the water in these basins is even, and is usually spoken of as level. In reality it is a curved surface, with its curvature nearly that of a sphere.

The oceans are more extensive in the southern hemisphere than in the northern. They encircle the earth in latitude 60° S. (Fig.

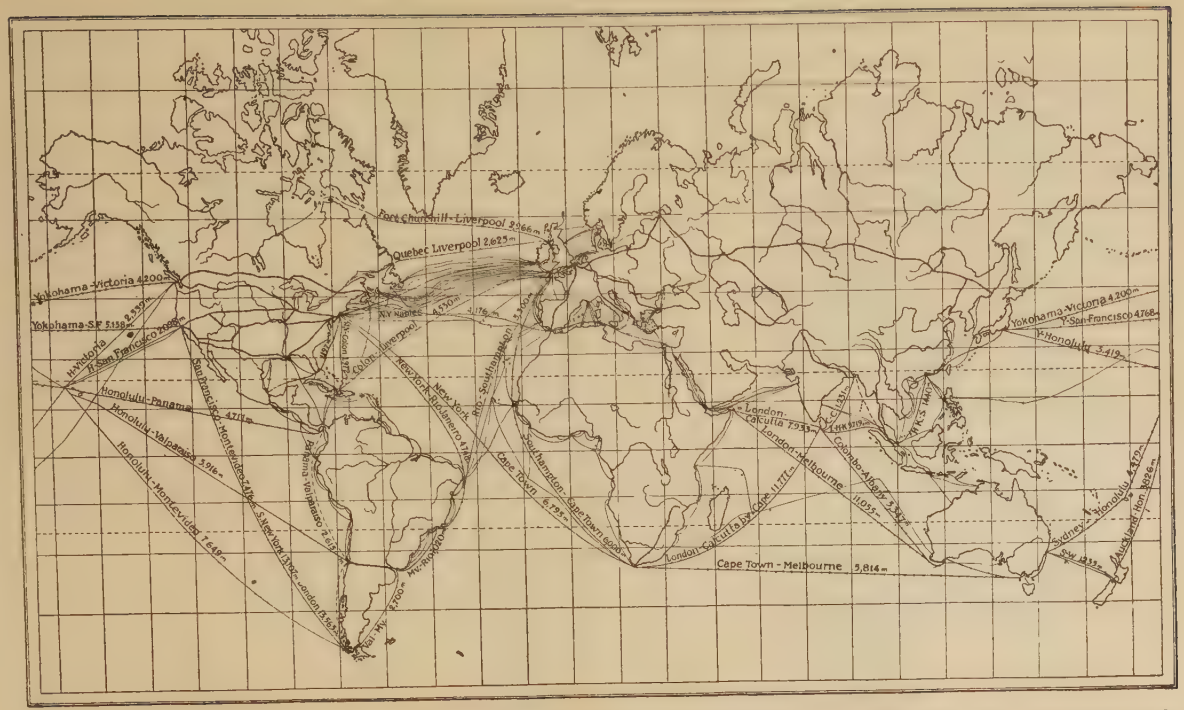

Fig. 113. Map of world, showing main steamship routes (with ports and distances indicated), submarine cable lines, and transcontinental railroads.

113), and the waters south of 40° S. are sometimes called the Southern Ocean. From it the Atlantic, Pacific, and Indian oceans extend northward thousands of miles. In the northern hemisphere the land makes an almost complete circuit in latitude 60° to 70° (Fig. 113), whence it extends southward in two great arms. North of latitude about 70° lies the Arctic Ocean, almost surrounded by land

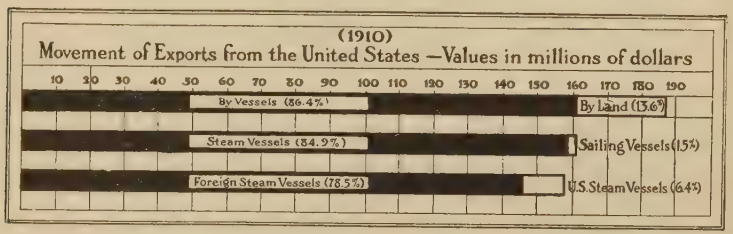
(1910)
Movement of Exports from the United States —Values in millions of dollars
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190
By Vessels (86.4%)
By Land (13.6%)
Steam Vessels (84.9%)
Sailing Vessels (1.5%)
Foreign Steam Vessels (78.5%)
U.S. Steam Vessels (6.4%)

Fig. 114. Diagram showing movement of exports from the United States by kinds of conveyances (1910).

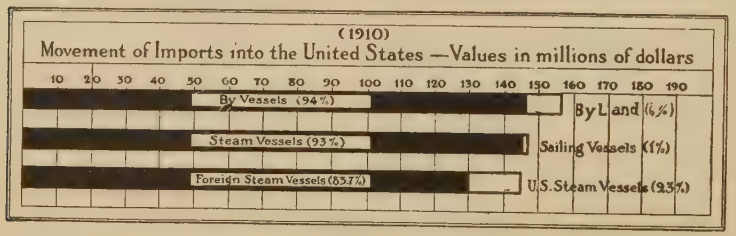
(1910)
Movement of Imports into the United States —Values in millions of dollars
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190
By Vessels (94%)
By Land (6%)
Steam Vessels (93%)
Sailing Vessels (1%)
Foreign Steam Vessels (83.7%)
U.S. Steam Vessels (9.3%)

Fig. 115. Diagram showing movement of imports to the United States by kinds of conveyances (1910). (Of 4,501 vessels from *foreign ports* arriving at New York City in 1911, only 11 were sailing ships.)

(Fig. 111) and therefore with but narrow connections with the larger oceans. The area of the different oceans (according to Ravenstein) is about as follows:

Arctic Ocean	5,200,000 square miles
Indian Ocean	28,000,000 square miles
Atlantic Ocean	35,000,000 square miles
Pacific Ocean	67,000,000 square miles
Southern Ocean	5,700,000 square miles

The volume of water in the oceans is nearly fifteen times the volume of the lands. If all the material of the land were deposited in the sea, it would raise the level of the water about 650 feet.

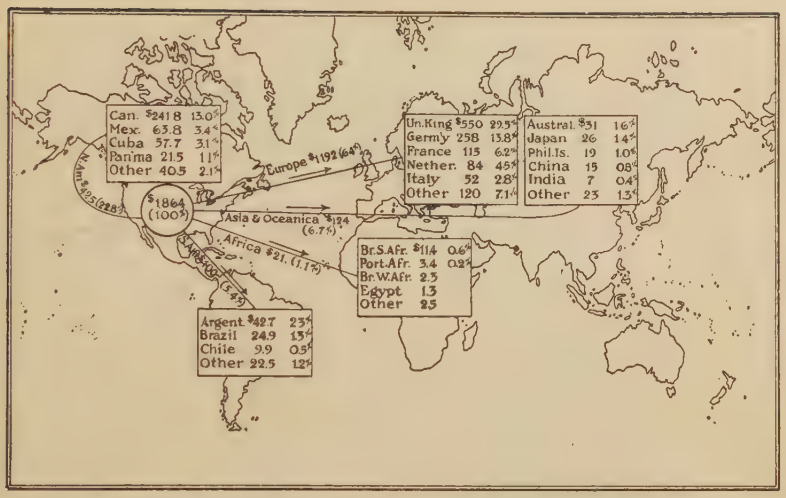

Fig. 116. Diagram showing destinations of exports from the United States by continents and leading countries (1910). (Values in millions of dollars; percentages are proportions of total exports.)

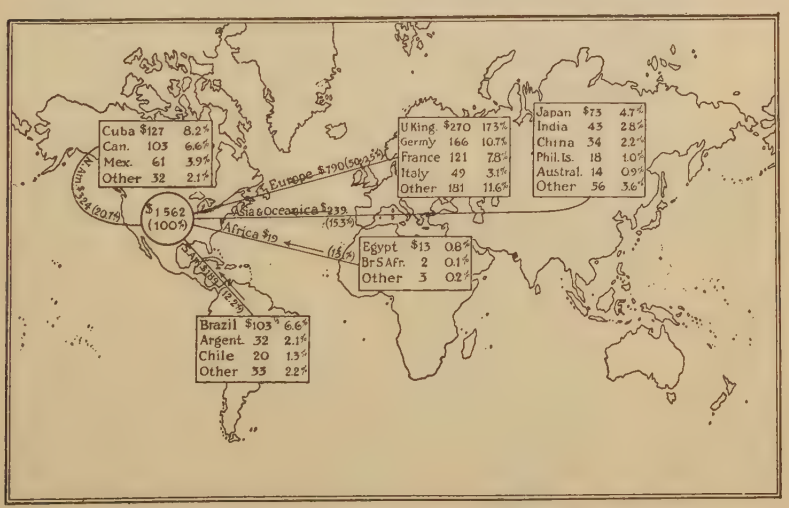

Fig. 117. Diagram showing sources of imports to the United States by continents and leading countries (1910). (Values in millions of dollars; percentages are proportions of total imports.)

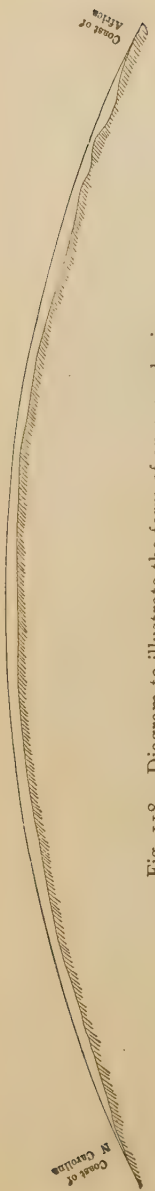

Fig. 118. Diagram to illustrate the form of an ocean basin.

Exploration of the ocean. The motions of the surface of the ocean, such as waves and tides, may be observed from the shore, but it has taken the work of many exploring expeditions to give us our present knowledge of the depths of the ocean and the conditions of its bottom.

The depth of the ocean is known by soundings, which are made from ships by reeling out a heavy weight held by a fine steel wire (Fig. 119). The weight is so fastened to the line as to be set free when it reaches the bottom, for this is simpler than to draw it up again. A sounding of 3,000 fathoms (a fathom = 6 feet) can be made in about an hour. A series of soundings in any region give a fairly accurate idea of the form of that part of the sea-floor.

The sediment on the bottom of the sea may be brought to the surface by various sorts of apparatus. The cup lead, a common form used, is shown in Fig. 120. *B* is a hollow, inverted cone. Above the cone is a sliding disc, *D*, a little larger than the base of the cone. When this apparatus is let down, the cone sinks into the soft sediment and is filled with it. On being raised, the disc shuts down on the cup and holds its contents in. Another device, known as a *water-bottle*, is used to secure samples of water from various depths, while a self registering thermometer records the temperatures at different levels. Hence a single sounding may give the depth, a sample of the sediment on the bottom, samples of the water, and a record of the temperature.

Larger samples of material from the bottom and specimens of deep-sea life are obtained by dredges (Fig. 121). When the dredge is let down, the strip of metal, *E*, drags along the bottom, and turns the sediment into the sack. Swabs are attached below to entangle small animals missed by the dredge.

Materials of the bottom. From sounding and dredging it is known that most of the sea-bottom

is covered with soft sediment, which has come from many sources. Some of it was carried to the sea by rivers, some was worn from the shores by waves, some was blown from the land, some is made up of the shells and skeletons of organisms which lived in the water, and some consists of fine debris thrown out from volcanoes beneath

Fig. 119.
The sounding line.

Fig. 120.
The cup lead.

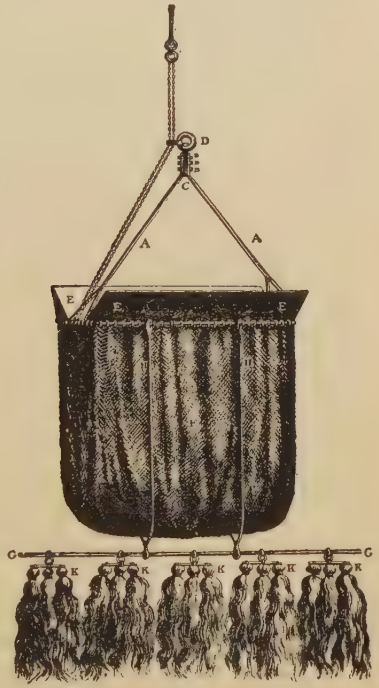

Fig. 121.
The deep-sea dredge.

the sea. A little cosmic ("shooting-star") dust is also present. Near many shores, gravel and sand derived from the land cover the bottom. Little gravel is found in depths of more than a few fathoms, though gravel and bowlders carried out by icebergs are found occasionally at great depths far from land. Sand, too, is found chiefly in shallow water, but extends out to depths greater than those reached by most gravel.

Beyond the narrow belt of gravel and sand along coasts, fine sediments, such as mud and clay, prevail; but sediments of organic origin are found in many places. Thus coral reefs and calcareous mud, the latter made by the grinding up of coral by waves, are found in shallow water in many places in low latitudes. *Ooze* is the name applied to those soft materials of the sea-bottom composed largely of the shells and other hard secretions of tiny organisms which live in the water. Many of the latter live near the surface of the water, and their shells and other hard parts sink when the organisms die. Oozes are named from the animals and plants which contribute most to them. Thus *foraminiferal ooze* is the ooze in which shells of tiny animals called *foraminifera* are abundant. These shells are mainly lime carbonate and enter largely into the composition of chalk deposits like those of the English coast and some of the states west of the Mississippi River. Chalk deposits, made in ancient seas, are used in making whitewash, Portland cement, whiting, and blackboard crayons. Since these chalk-beds were made, the sea-bottom where they were laid down has become land.

In *diatom ooze* the skeletons of minute plants (*diatoms*) abound. It is composed mainly of silica. Some deposits of it, known as *diatomaceous* or *infusorial earth*, are used as a polishing powder. Its porous nature has led recently to its use in making dynamite, and for packing pipes and boilers where a non-conductor of heat is wanted. Large beds of infusorial earth (some of them perhaps of fresh-water origin) are worked in this country, especially in California.

Below the depth of about 2,200 fathoms, the ocean-bottom is covered with *red clay*, the particles of which came from many sources. Most of it consists of the decomposed products of (1) materials thrown out from volcanoes, (2) dust blown from the land, (3) shells and other secretions of marine life, and (4) meteors.

The sediments of the sea-bottom are to be regarded as rock in the making, for they may become solid rock by being cemented together (p. 259). This process is taking place at many points in the sea. Locally, it goes on as fast as the sediments gather. On the lands there are various kinds of rock (conglomerate, sandstone, shale, limestone, p. 259), composed of sediments such as are now being deposited in the shallow parts of the sea, but no known formation in the land corresponds to the red clay of the very deep sea. This suggests (1) that *most lands have been, at some time, beneath the sea*, and

(2) that, *so far as now known, no part of the present continents was ever at the bottom of the deep ocean.*

Depth and pressure. The average depth of the ocean (Fig. 122) is about two and one-half miles, or nearly 13,000 feet. The depth exceeds four miles in many places, and the area of very deep water is much greater than that of very high land. The areas which are far below the average depth of the ocean are known as *deeps*. The greatest depth of water known, 31,614 feet, is in the northern Pacific, near the Ladrone Islands. This depth is more than the height of the highest mountain (Mt. Everest, 29,002 feet) above the sea. There are other areas exceeding five miles in depth in the Pacific, which is the deepest ocean. The greatest depth of water known in the Atlantic is Blake Deep (27,366 feet), north of Porto Rico. This deep, like those of the Pacific, is long and narrow, has steep slopes, and is parallel to the great ridge of which Porto Rico is a part. In few other places in the Atlantic does the depth reach 20,000 feet. The Indian Ocean is not known to have depths much exceeding 20,000 feet, and the deepest known places in the Arctic Ocean and in the Southern Ocean are still less.

The pressure at the bottom of the deep oceans is very great. At a depth of one mile, it is one ton to the square inch, while in the greatest deeps it exceeds six tons to the inch. This pressure would crush some kinds of stone. Yet the ocean water does not become much denser (is not compressed much) even under so great pressure. Objects such as pebbles, which sink readily at the surface, sink readily to the bottom. The pressure at great depths is an important factor in submarine work by divers, since the pressure of air within the diver's suit must be about equal to that of the water outside.

Topography of the bottom. Most of the sea-bottom is nearly flat, and therefore very unlike the land. The surface of the land is made rough in various ways, especially by running water and winds; and the difference between the topography of the land and that of the sea-bottom is due largely to the fact that these agents do not affect the latter.

In spite of the general flatness of the sea-bottom, it has many irregularities, for there are (1) *volcanic cones*, some of them built up from the bottom of the deep sea to elevations far above its surface (p. 302); (2) *steep slopes*, such as those (a) between the continental platforms and the deep sea basins and (b) about some of the deeps; (3) *valley-like depressions*, especially on the continental shelves;

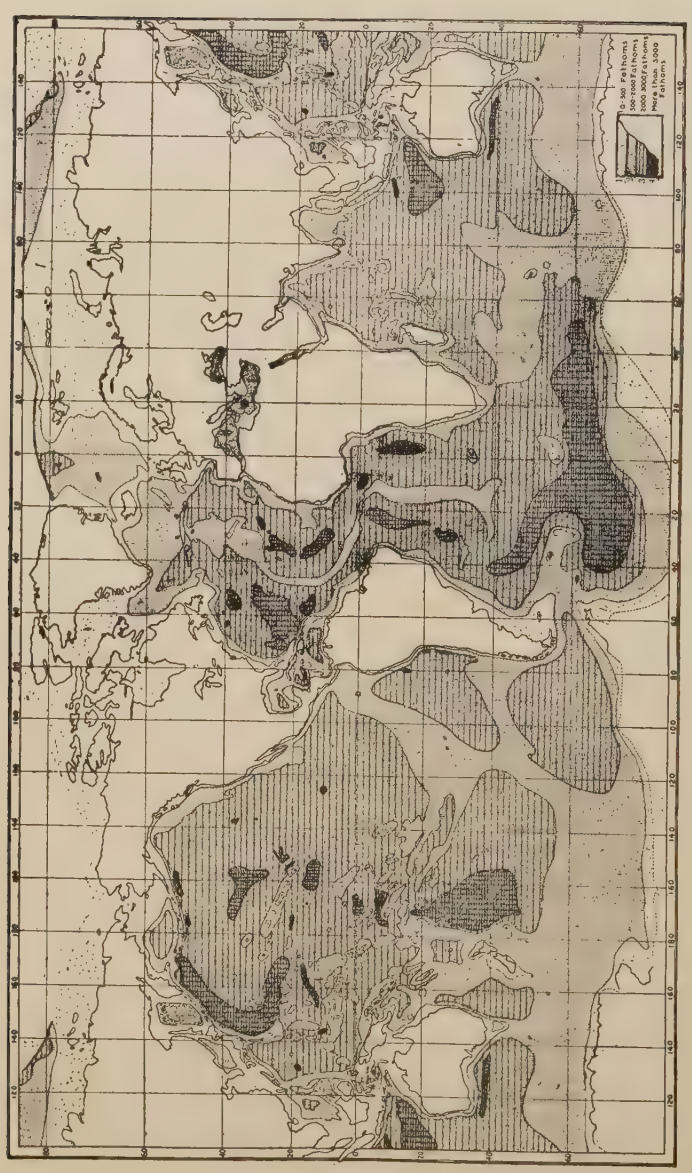

Fig. 122. Chart showing depths of the oceans. (After Murray.)

(4) *great ridges* somewhat like the mountain ridges of the land; and (5) *broad, plateau-like swells.*

(1) Volcanic cones are most numerous in the Pacific Ocean, and more numerous in its deeper western part than in its shallower eastern part. They seem to rise abruptly, but their slopes are much less steep than they seem. The upper parts of few volcanic islands have a slope of more than 30°, and the lower parts of most of them slope less than 6°. Below the sea, the slope in most cases is less than 3°, or 1 mile in 20.

(2) The slopes around the deeps and at the edges of the continental shelves are steep, as slopes in the ocean-bottom go, but much less steep than many slopes on land. Submarine slopes as great as 1 mile in 8 are rare, and 1 mile in 20 not very common. The latter slope would make a steep railway grade.

(3) On many continental shelves there are valleys which are much like river valleys. Many of them are continuations of valleys on land. Thus the Hudson, Delaware, Susquehanna, St. Lawrence, and other valleys are continued out under the sea. Such submerged valleys are thought to have been formed by rivers when the areas where they occur were land.

(4) Examples of mountain-like swells are furnished by Cuba and the adjacent islands, which are really the crests of a great mountain system rising from deep water.

(5) An example of the plateau type of elevation is the Dolphin Ridge of the Atlantic (Fig. 122). This broad, low, north-south swell extends to latitude 40° S., and divides the basin of the Atlantic into two troughs, where the water is deeper than over the ridge. In the southern Pacific, many volcanic islands rise from similar submarine plateaus.

Composition of sea-water. One hundred pounds of average sea-water contain nearly three and one-half (3.44) pounds of dissolved mineral matter. More than three-fourths (nearly 78 per cent) of this is common salt, but nearly all other substances found in the earth's crust are present, most of them in very small quantities. Even gold occurs in sea-water, but not in quantity sufficient to make its extraction profitable. If all the salts dissolved in the sea were taken out of solution and laid down as solid matter on the ocean-bottom, they would make a layer about 175 feet thick. In the past, the evaporation of water from salt lakes, perhaps cut off from the sea by changes of level, has formed important salt-beds. New York has a

valuable salt industry near Syracuse, depending on such deposits of rock salt (p. 288), while the great salt mines near Salzburg and Cracow, in Austria-Hungary, are famous the world over. Much salt is obtained also by evaporating sea-water. The Stassfurth salts, containing much potash, are important factors in making Germany the leading nation of the world in chemical industries.

The mineral matter in sea-water makes it a little heavier than fresh water, and makes it freeze less readily. Its lower freezing point (26°–28° F.) often leaves the ocean free from ice when near-by bodies of fresh water are frozen over.

Sources of mineral matter. Dissolved mineral matter is being carried to the sea by rivers all the time. Rivers have brought the sea most of its mineral matter, though some of it may have been dissolved from rocks beneath the sea, or about its shores. The mineral matter carried in solution to the sea by rivers in a year would make nearly half a cubic mile of solid matter.

The minerals which are most plentiful in the sea are not those which are most common in the rocks of the land. Those minerals of the land which are dissolved most easily get into rivers, and thence to the sea, in greater quantity than those which are less soluble. Some of the minerals in sea-water, such as salt, do not exist in the common rocks of the land. Common salt is made by the union of a substance in certain rocks with a gas in the air or water. Granite, for example, contains sodium, one of the elements of salt, and when sodium unites with chlorine (a gas) the result is salt. It takes much granite to yield the sodium for a little salt.

Withdrawal of mineral matter from the sea. Of the mineral matter carried in solution to the sea, calcium carbonate, of which most shells are made, is most important to ocean life. The amount of this substance dissolved in river-water is nearly as great as that of all others. Common salt is present in river-water in amounts too small to be tasted; yet the amount of it in sea-water is more than 200 times that of calcium carbonate. The reason is that calcium carbonate is taken out of the water all the time by animals, to make shells, coral, etc., while most of the salt carried to the sea stays in the water; and this probably has been true for millions of years.

Gases in sea-water. Sea-water also contains dissolved gases. The most abundant are those of the air, especially nitrogen, oxygen, and carbon dioxide. The amount of oxygen dissolved in the ocean

is more than $\frac{1}{300}$ of that in the air; the amount of nitrogen about $\frac{1}{1100}$ that of the air, while the amount of carbon dioxide in the sea is 18 times that in the air.

Much of the gas in the ocean was dissolved from the atmosphere. After being taken into solution at the surface, the gases are distributed through the whole ocean, partly by movements of the water, and partly in other ways. Thus oxygen has been found in samples of water from great depths.

The oxygen of the water is being used all the time by sea animals, and its supply is being renewed all the time by solution from the air. Animals and plants do not use the nitrogen dissolved in sea-water, and the same nitrogen probably stays there from age to age. The carbon dioxide is being used all the time by the plants of the sea, and some of it is constantly escaping into the air.

Salinity, density, and movement. For several reasons, some parts of the sea are more salty than others. (1) The salt is left behind when ocean-water evaporates. Since evaporation is more rapid in some places than in others, the water becomes more salty where evaporation is great, as in some hot climates. (2) Where much rain falls, the water is freshened. (3) Where large rivers enter the sea, the latter is freshened. In these ways the saltness of the sea-water at the top of the ocean is changed all the time.

Every change in the saltness of sea-water changes its density, and unequal density causes movement. When surface water becomes denser than that beneath, it sinks, and lighter water comes in over it from all sides. When the surface water of one place becomes less dense (fresher) than that about it, the lighter water spreads out on the surface, as oil spreads on water. Since variations in saltness are being produced all the time, motion due to unequal density is constant. Movements brought about in this way are usually very slow, and are called *creep*.

Salinity and color. The sea is generally blue or green, but its color varies from place to place and from time to time. The blue is deeper where the amount of salt is great. Thus seas like the Mediterranean, which are more saline than the open ocean (Why?), are of deeper blue. The cold and less salty (Why?) waters of high latitudes are often distinctly green. Many variations of color are due to tiny particles of solid matter suspended in the water. Microscopic animals and plants (as in the Red Sea), sediment from the

land (as about the mouth of the Hwang-ho), and material from volcanoes beneath the sea, all help to give the sea-water of different places its various colors.

Temperature of the Sea

Temperature of the surface. The surface of the ocean, like that of the land, is warmer near the equator and cooler toward the poles (Fig. 123). Near the equator its temperature is about 80° F.;

Fig. 123. Map showing mean annual temperatures for the surface waters of the oceans. (After Lyde.)

near the poles, where not frozen, it is 26°–28° F. When the temperature becomes colder, sea-water freezes, and the surface of the ice may become as cold as the air above it; but the temperature of the water just beneath the ice is 26°–28° F. The decrease of temperature toward the poles is by no means regular, as shown by the isothermal chart (Fig. 123), where isothermal lines over the ocean are not parallel with the parallels of latitude.

In the open sea, ocean currents help to make the isotherms depart from the parallels (p. 77). Some currents are *cold*, flowing into warmer water, and some are *warm*, flowing into cooler water.

There are still other reasons why the surface of the ocean does not

get colder steadily from equator to poles. Rivers help to make surface temperatures unequal, for they are often warmer than the sea in summer, and colder in winter. Partly enclosed arms of the sea in low latitudes are warmer than the open ocean in the same latitude (Fig. 124; Why?). The highest temperatures of the sea are found in such situations. The surface temperature of the Red Sea, for example, sometimes reaches 100° F.

Temperature and movement. Water expands slightly when warmed. Warm water is therefore lighter than cold water, if both are equally salt. It follows that unequal surface temperatures cause movement of the surface waters, and since the surface temperature

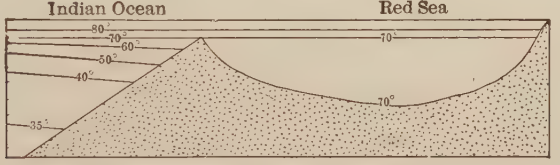

Fig. 124. Diagrammatic section of Red Sea and adjacent part of Indian Ocean, to illustrate the effect of a barrier on the temperature of the water. Temperatures are in degrees Fahr.

is kept unequal all the time by unequal heating, by inflow of rivers, and by melting ice, there is constant though slow movement of the surface waters.

Temperature beneath the surface. Sea-water becomes cooler with increasing depth, except where the surface is at or near the freezing point. Even where the surface water is warmest, the temperature at a depth of a few hundred fathoms is below 40° F. The following table shows the average temperature of the sea at various depths, in lower latitudes:

Depth	Average Temperature
600 feet	60.7°
1,200 feet	50.0°
3,000 feet	40.1°
6,000 feet	36.5°
13,200 feet	35.2°

It is estimated that not more than one-fifth of the water of the ocean has a temperature as high as 40° F., while its average temperature is probably below 39° F. At the bottom of the deep sea the

temperature of the water is generally below 35° F.; only in certain areas of shallow water, and in the partly enclosed seas of relatively low latitudes, is the temperature of the bottom as high as 40°. Thus the deeper parts of the Caribbean Sea (over 2,000 fathoms) have a temperature of 39° to 40°. This is the temperature found in the open Atlantic at a depth of about 900 fathoms, the level of the bottom of the deepest channel connecting the Caribbean and the ocean. The Mediterranean also has practically the same temperature at all depths below the level of its deepest connection with the Atlantic.

Movements of Sea-Water

Causes

We have seen that differences in saltness and in temperature make waters unequal in density, and so produce a slow circulation of the waters of the sea. There are other causes which produce movement, such as (1) differences of level, (2) winds, (3) the attraction of the moon and the sun, and (4) occasional causes, such as earthquakes and volcanic explosions.

Inequalities of level. The inequalities of level which produce movements of sea-water are brought about chiefly by (1) the discharge of rivers, which raises the surface of the sea near their mouths; (2) winds, which pile up the waters along the shores against which they blow; (3) unequal rainfall, which raises the surface most where most rain falls; and (4) unequal evaporation, which lowers the surface most where it is greatest.

Movements due to unequal rainfall and evaporation are generally too slight to be observed. Those caused by the inflow of rivers and by winds are greater. Thus, beyond the mouth of a great river like the Amazon, movement may be distinct for many miles, and waters often are piled up against a shore by winds, to such an extent that the rise may be seen readily. The raising of the surface of the water caused most of the destruction in the storm at Galveston (p. 139). Strong southeasterly winds frequently pile up the water sufficiently to block the sewers in Baltimore, while embankments have been constructed to protect the eastern part of New Orleans from the waters of Lake Pontchartrain. When the water-level has been raised along a coast by the wind, it settles back after the wind goes down. Since the causes producing differences of level are always in operation, movements due to these differences are always taking place.

Winds. Winds produce movement of sea-water in another way. Where they have a constant direction, as in the zone of trades (p. 166), there is a constant drifting movement of surface water in one direction. A steady movement in one direction necessitates a return movement somewhere else, thus producing a *circulation* of the sea-water. Where the circulation is in the form of distinct streams of water, they are called *ocean currents*.

Attractions of moon and sun. Bodies attract each other in proportion to their masses, and inversely as the squares of their distances. That is, a body which weighs twice as much as another has twice the attractive force at the same distance. If one of two bodies of the same mass (or weight) is twice as far from a third body as the other is, their attractive forces on the third are as 1:4.

The side of the earth toward the moon is nearer the moon (by about 4,000 miles) than the center of the earth is, and so is attracted by that body more strongly than the center. The opposite side (about 4,000 miles farther away) is attracted less strongly than the center, and these differences of attraction disturb the waters of the earth. The attraction of the sun produces similar, though lesser, effects. The resulting movements of the sea-water are *tides* (p. 246).

Occasional causes. Landslides along shore, earthquakes, volcanic explosions, etc., may cause sudden and extensive movements of the ocean-water (pp. 298, 306). Low coastal lands occasionally suffer severely from movements of this sort.

Types of Movement

The movements which result from the above causes are (1) *waves*, with the *undertow* and *shore currents* which they produce; (2) *ocean currents;* (3) *drift*, or feeble currents; (4) *tides;* and (5) *creep* (p. 237).

Waves. When the wind blows over a water surface it causes waves. The stronger the winds, the greater the waves. With moderate winds, waves in open water rarely exceed 10 feet in height (from crest to trough). Ordinary storm-waves may be twice as high, while in violent storms a height of 40 or more feet is attained. Such waves breaking on the decks of vessels may do much damage. Many vessels have obtained relief from storm-waves by allowing oil to drip from a bag hanging at the bow or stern. The oil spreads over the surface in a thin film, and since the friction of the wind on the oil-covered surface is much less than on a surface of water, the waves

decrease in size. Storm-waves attain a rate of 30 miles an hour very commonly, and reach the speed of 60 miles an hour in violent hurricanes, but, save in shallow water, the water in a wave usually does not move forward (p. 520).

The distance between successive wave crests is the *length* of the wave, and the time between the passage of successive crests is the *period* of the wave. Both length and period vary widely, and are important in navigation. Wave lengths vary from 100 feet or less to 2,000 feet or more, in severe storms. Occasionally the surface of the ocean is smooth and glassy, and yet shows long, low undulations. These are "swells," and usually represent waves caused by distant storms. On some coasts they interfere seriously with commerce. The shortest waves are usually found where there is an actual movement (current) of the water contrary to the direction of the wave impulse, giving a "choppy sea." Such waves are especially unfavorable for small craft, and may cause much discomfort to passengers on larger vessels. In general, the longer the vessel, the less it is affected by waves; hence the advantage of the modern ocean steamships, which in some cases are nearly twice as long as the average storm-wave (400 to 600 feet).

Currents and drifts. There are more or less distinct streams of water, or *currents*, in various parts of the ocean. This was known first by their effect on the course of sailing vessels. It was later proved in other ways, as by following the course of floating objects set adrift for this purpose.

It is desirable to know as much as possible about these currents because of their effect on navigation. In foggy weather, and especially near some coasts, failure to allow for the current may lead to ship-wreck. Some of the wrecks that have occurred on the Irish coast probably were caused in this way. Vessels are aided or retarded by currents, according to the direction of the voyage.

Surface currents also affect the movements of icebergs and floe ice. Collision with an iceberg might wreck the largest steamship, and floating ice favors the formation of fog, which increases the danger of collision between vessels, and between vessels and ice. For these reasons, steamship routes across the North Atlantic vary somewhat with the season, in order to avoid the floating ice.

Little is known of ocean currents beneath the surface. A few of them affect the water to a depth of 3,000 feet, but most of them are shallow, compared with the depth of the ocean. Even the larger

currents are not always seen easily, though they differ from the water on either side in color, temperature, and salinity. As a rule, these differences are more marked the swifter the current. A current so slow as to be indistinct is often called *drift*.

Courses and causes of ocean currents. Fig. 125 shows the general circulation of the surface waters of the sea. It represents a large part of the surface water as moving. There are *equatorial currents* or drifts moving westward, one on each side of the equator, in both the Atlantic and Pacific oceans. Between the equatorial currents, there is, in each of these oceans, a narrow *counter-current*, or drift, moving eastward. The equatorial waters of the Atlantic Ocean which are drifting westward are divided at the eastern coast of South America. The smaller part is turned to the southwest, and the larger part to the northwest, along the border of the continent. Part of the northern branch flows through the Caribbean Sea into the Gulf of Mexico, whence it issues through the narrow strait between Cuba and Florida as the *Gulf Stream*. This well-defined current is fed partly by the water which enters the Gulf from the equatorial drift, and partly by that which enters from the land.

In the Straits of Florida, the Gulf Stream is about 40 miles wide in its narrowest part, 2,000 to 3,000 feet deep, and has a maximum velocity of about five miles per hour. Farther north, it becomes wider and slower, until, in the open ocean, the rate is perhaps only 10 to 15 miles per day. As it becomes slow, its boundaries become less distinct, and it is recognized by its temperature, color, and life more readily than by its motion.

As it advances, the Gulf Stream turns toward the east (to the right), crosses the Atlantic, and approaches the coast of Europe in a latitude farther north than that where it leaves the coast of America. As it approaches Europe, it divides and spreads, but long before Europe is reached (about latitude 40° N.), the current has become a wide-spread drift of water, not easily distinguished. This favorable current and westerly winds make the voyage for sailing vessels from this country to England much quicker than the return trip. That part of the equatorial drift which is turned southward along the coast of South America soon turns to the left (Fig. 125).

The equatorial drifts of the Pacific follow courses similar to those of the Atlantic. The part which turns north is the *Japan Current*. The Indian Ocean has a south equatorial drift only, and its course corresponds to that of the southern part of the equatorial drifts of

Fig. 125. Chart showing ocean currents for the world. Arrows indicate direction of flow. Approximate velocity in miles per hour indicated by the number of bars on shaft of arrow.

the other oceans. All currents moving toward the poles from the equatorial region are *warm currents*.

The poleward movement of warm waters makes a return equatorward movement necessary. The cold waters moving toward the equator are turned to the right in the northern hemisphere, and to the left in the southern. The result is to throw them to the eastern coasts of the continents, where in places they form distinct cold currents. Along the east coast of North America, the *Labrador Current* brings icebergs south to Newfoundland, while in the warmer waters of the northeastern Atlantic, ice rarely forms even in latitude 70°. The Labrador Current chills the air above it, and this makes northeast winds in New England colder than they would be otherwise.

The equatorial drifts are caused and directed by the trade-winds. Outside the tropics the winds do not blow in one direction all the time, and so do not produce persistent drifts or currents; but in regions of strong monsoon winds, as about India, the drift of the surface waters changes with the wind (Figs. 64 and 66).

If the ocean covered all the earth, the westward drift of equatorial waters, caused by the trade-winds, would go round and round the earth. But the continents deflect the waters, turning them north and south. Once turned in these directions, the waters would tend to follow the coasts but for the deflecting influence of the earth's rotation. Where the sea is so shallow that the moving water touches bottom, the topography of the bottom influences the course of movement. Ocean currents therefore appear to be *started* chiefly by the winds, and to be *directed* by winds, lands, and the rotation of the earth, and, to a less extent, by the topography of the bottom.

Ocean currents and atmospheric temperatures. Without ocean currents, the isotherms over the sea would follow the parallels somewhat closely, except near the continents (p. 75). Under such conditions, the temperature over the ocean in the latitude of the British Isles and northward would be 10° F. or more lower than now (Fig. 123). Ocean currents do not themselves warm or cool the land; but the air over a warm current is warmed by the water, and is then blown to the land. Even without the Gulf Stream, the western coast of Europe would have a milder winter climate than the eastern coast of North America in corresponding latitudes (p. 191), but the drift of warm water into the North Atlantic makes the winter temperature of Europe north of latitude 50° considerably warmer than it would be otherwise. Thus the harbor of Hammerfest, Norway, latitude

76°, is affected by ice about as much as that of New York, latitude 40°. The Japan Current likewise lessens the cold of winter on the northwestern coast of North America. Similar results would be found in the southern hemisphere, if there were land so situated as to feel the effects of the warm currents in the southern oceans.

Warm currents often help to cause fogs, both at sea and on land. When wind blows over a warm current, it takes up a large supply of moisture. If it then blows over colder water, it is cooled, and some of its moisture is condensed, producing a fog. Fogs are common along the leeward side of the Gulf Stream, where the adjacent land or water is much cooler than the current itself. Fogs are more abundant about Newfoundland than farther south, because the difference between the temperature of the Gulf Stream and its surroundings is greater there than farther south.

The shifting of the course of the Gulf Stream sometimes is mentioned in newspapers as the cause of a mild winter in the United States. Strong winds may force the surface waters of the Gulf Stream out of their usual course; but this shifting is always temporary, and has little or no effect on the winters.

Work of ocean currents. Currents have little effect on the ocean-bottom, and almost none on coasts, because in most places they touch neither; but where the water is shallow, a current may scour the bottom, as the Gulf Stream does between Florida and Cuba. Since ocean currents erode but little, they carry little sediment. Warm currents carry multitudes of plants and animals, many of which are very small, and these organisms and their shells are scattered far and wide over the bottom of the ocean. Currents may also carry wreckage of ships and driftwood long distances. In some places the latter is a valuable source of fuel. Seeds may be carried long distances in the same way.

Tides. Along most coasts, the ocean-water rises and falls twice every day, or, more exactly, every 24 hours and 52 minutes. The rise and fall of the water are the *tides*. The tide rises for about six hours, when it is *high* or *flood* tide, and then falls for about six hours, when it is *low* or *ebb* tide. In most places there is a distinct interval of little or no movement ("slack water") when high tide changes toward low, and vice versa. The rise and fall amount to several (3 to 6) feet in most places. In bays which open broadly to the sea, but are narrow at their heads, the range is sometimes 20 or 30 feet, and in rare cases, as in the Bay of Fundy (Figs. 126 and 127), 50 feet or more. Conversely,

where bays have a narrow entrance and widen within, the tidal range is small. Tides are absent in small lakes, and are feeble in large lakes and in seas connected with the ocean by a narrow passage, such

Fig. 126. Low tide at Wolfeville, Bay of Fundy, Nova Scotia, Sept., 1903. In March, 1904, end of pier was washed away in a storm, and lighthouse damaged. (Photograph by the late Roland Hayward, Milton, Mass.)

as the Mediterranean Sea and the Gulf of Mexico. Thus at Galveston, Texas, the range of the tide is less than one foot.

In many shallow harbors, the tides have an important effect on navigation (Figs. 126 and 127). Even some of the most important

Fig. 127. High tide at the same place shown in Fig. 126. (Photograph by the late Roland Hayward, Milton, Mass.)

ports depend on the rise of the tide for the movement of their commerce. Thus at Liverpool vessels arriving at low tide must wait, in many cases, for high tide, before the water is deep enough for them to

dock, and vessels must arrange hours of departure to match high tides. Hence, it is important for the navigator to know exactly the hours of high and low tide for every harbor which he may wish to enter. Where the tide runs in among islands, or passes through narrow straits, it causes distinct currents (*tidal races*), eddies, and whirlpools, like the famous Maelstrom near the Lofoten Islands. These movements may interfere with navigation, especially by small boats. Sailing vessels frequently have serious difficulties with tidal races, as at Hell Gate, New York, and in Vineyard and Nantucket sounds, off the coast of Massachusetts. Fishermen commonly speak of the tide

Fig. 128. Tidal bore entering river at Moncton, New Brunswick. (Photograph by the late Roland Hayward, Milton, Mass.)

as "coming in," or "going out," and time their movements to take advantage of it. Small craft find it impossible to go out when the tide is coming in, or to come in when the tide is going out. Even large vessels are affected by the "set" of the tides, and more than one wreck has been due to this cause. In many ways these movements of the ocean are more important to navigation than ocean currents, and much effort is devoted to charting them for the benefit of navigators.

The tide runs far up many rivers. Thus the range at Troy, some 150 miles up the Hudson River, is more than two feet, and tides ascend the St. Lawrence nearly 300 miles. As the tide advances up the channel, its front may become a steep, wall-like wave called a *bore* (Fig. 128). This is the case in the Severn, Seine, Tsien-Tang-Kiang, and other rivers. In the last-named river the waves are sometimes 25 feet high, and advance at the rate of 10 to 20 miles an hour. Such conditions are dangerous for shipping, and serious losses of life and property frequently result.

It is at least two thousand years since the moon was first

thought to cause the tides, but only about two hundred years since Newton explained how the moon produces them. The moon rises and sets twenty-four hours and fifty-two minutes later each day than it did the day before. The time between two high tides or between two low tides is half this period. It appears to have been this fact which suggested that the tides are caused by the moon.

Without attempting to give a full explanation of the tides, some of the principles involved may be understood. If a weight is attached to a string and whirled, it tends to fly away in a straight line. It is prevented from doing so by the string, which holds it in its circular path. The tendency to fly away is what

Fig. 129. Diagram to show the tendency of the moon to raise the water on the side of the earth toward the moon and on the opposite side at the same time, producing two high tides.

is called *centrifugal force*. The earth and moon attract each other (p. 241), and would fall together but for the centrifugal force due to their motions. At the center of the earth, and at the center of the moon, the attraction between these bodies is exactly balanced by the centrifugal force due to their revolutions. The result is that neither falls toward the other. But on the side of the earth nearest the moon the attraction is stronger than at the center of the earth (p.241), and is greater than the centrifugal tendency. *The attraction of the moon, therefore, tends to make the earth bulge out on the side nearest the moon.* On the opposite side of the earth the attraction is weaker than at the center, and is less than the centrifugal force. Here, too, the earth tends to bulge out. The solid part of the earth is so rigid that it does not rise enough to be felt or seen. But the waters of the ocean move easily, and rise a little, and the rise takes place on opposite sides of the earth at the same time. This makes the *high tides*. Between the high tides the water sinks a little, making the *low tides*. The rotation of the earth makes the tides appear to move about the earth.

If all the earth were covered with water, its surface would have two great tidal bulges or waves at the same time (Fig. 129). The

highest part of one would be a point directly under the moon, and the highest point of the other would be opposite the first. Each wave would cover half the earth, and the borders of the two would meet in a great circle, where the surface of the water would be lowest.

If the moon were not revolving about the earth, high tide at any place would come every 12 hours. But the moon moves forward in its orbit about the earth, so that it takes 24 hours and 52 minutes for a given place to have the same relation to the moon that it had the day before. This makes the period between successive high tides 12 hours and 26 minutes.

The movements of the tides are not so simple as the outline above would imply. Many things interfere. The continents stop or divert

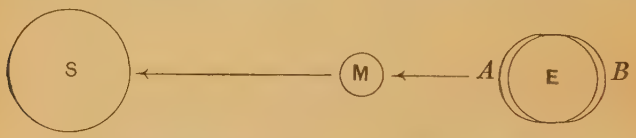

Fig. 130. Diagram to show the relative positions of the earth, moon, and sun, at the time of new moon (=spring tide). Size of moon (M) and earth (E) greatly exaggerated.

the advance of tidal waves, and the waves travel more slowly in shallow than in deep water (Why?). Since tides are retarded most near land, their advance is here most irregular. For these reasons, the time of high tide at most places differs from the time when the moon crosses their respective meridians. This difference in the time of arrival of high or low tide may be determined for any harbor, and is called the "establishment of the port." At New York, for example, high water arrives 8 hours and 13 minutes after the moon passes the meridian. Tables showing the "establishment" of different ports are of great value to navigators.

The sun also attracts the earth, and tends to cause tides. If there were no moon we should still have small tides produced by the sun. The tides which we know are the combined effects of moon and sun; but the moon's tides are much the stronger. The sun strengthens the tides when sun and moon work together, and weakens them when they work against each other.

When sun and moon stand in the relation to each other and to the earth shown in Fig. 130 (*new moon*), each tends to make high tides at *A* and at *B*. When the relations are those shown in Fig. 131

(*full moon*), the result is the same. At these times, and each occurs once a month, high tides are higher, and low tides lower, than at other times. The tides of such times are called *spring tides*. They have no relation to the spring season.

When the earth, moon, and sun have the relative positions shown in Fig. 132, and this occurs twice each month, the tidal influences of

Fig. 131. Diagram to show the relative positions of the earth, moon and sun, at the time of full moon (=spring tide).

the sun and the moon are opposed to each other, and the result is that high tides are not so high, nor low tides so low, as under other conditions. The tides of such times are known as *neap tides*. Spring tides have nearly twice the range of neap tides in many places.

In the open ocean and along precipitous coasts, the tide is like other waves, merely a rising and falling of the water. Like other

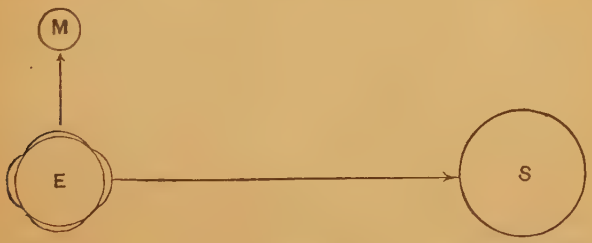

Fig. 132. Diagram showing the tendency of the sun and moon to produce tides on opposite parts of the earth at the time half way between new moon and full moon, and half way between full moon and new moon.

waves also, the water of the tidal wave moves forward when it approaches shores where the water is shallow.

In shallow waters near the coast, tides alternately cover and expose wide expanses of sandy beach or mud flats, as the case may be. The water-line at low tide may be a quarter of a mile or more from its position at high tide. Tidal currents may be effective agents of erosion. Tidal scour keeps many waterways (*thorofares*) open

through tidal marshes, as along the coast of New Jersey. It also maintains deep channels in certain harbors, to the great advantage of commerce. By the circulation they cause, tides in some cases help to remove filth which otherwise would accumulate in harbors. Sewage disposal is always easier for cities near tide-water. On the other hand, the gradational effect of tides is harmful in some cases, for much of the sediment drifted about by them is deposited in harbors. This makes expensive dredging necessary in many harbors, in order to maintain a sufficient depth of water for shipping. The frequent shifting of the deposits renders it impossible to indicate the channel on the pilot charts of some harbors.

The large volume of water rising and falling in tides has led to many attempts to develop tidal water power. Small tide mills are used for grinding grain and other purposes at various places in western Europe, and a few larger power plants have proved useful, as in the Seine estuary. But on most coasts conditions are not favorable for the development of extensive power from tides. The chief difficulties are the slight rise and fall, and the slow rate of movement.

The Life of the Sea

Animals and plants abound at and near the surface of the sea, and at the bottom where the water is shallow. A bucket of water dipped up from the surface of the ocean almost anywhere will contain hundreds or even thousands of minute plants and animals, though most of them are too small to be seen without a microscope. Living things are present, but not in great numbers, at the bottom of the deep sea; but in the water between the uppermost 100 fathoms and the bottom, animals and plants are nearly absent. It has been estimated that the life of the sea exceeds that of the land, square mile for square mile, but there is probably no one level in the sea where life is so abundant as on the fertile parts of the land.

The temperature, the depth, the clearness, the saltness, and the quietness or roughness of the water, influence the life which it contains, in ways easily understood. The depth of the water affects the distribution of the plants and animals which live on the bottom, but has little effect on those which float or swim near the surface. The most important influence of depth appears to be in connection with light and oxygen. Animals cannot see much at a depth of more than about 50 fathoms, though a little light penetrates to greater

depths. In the great body of the ocean darkness reigns, and green plants, which depend directly on sunlight, cannot live in darkness. At the bottom of the deep sea the water is not stirred, and any oxygen it contains must pass down from the surface after being dissolved there. As it is used up by the animals at the bottom, the supply is renewed from above very slowly.

Though the pressure of the water at the bottom of the ocean is very great (p. 233), the animals living there can stand it, because their bodies are full of liquids under the same pressure, and these great pressures within their bodies balance the great pressures without. If an animal from the bottom of the deep sea were brought suddenly to the surface it would explode (Why?). Even when raised slowly, they sometimes explode as they near the surface.

Some animals, such as the polyps which make coral, live only in warm regions where the water is shallow and clear, with neither excess nor shortage of salt. Others, such as narwhals and seals, are found only in cold waters. Still others are found in both warm and cold waters. The unequal distribution of ocean temperatures by warm and cold currents influences greatly the character of marine life in different parts of the sea. Thus coral polyps cannot live about the Galapagos Islands (Why?), near the equator, while they are abundant about the Bermuda Islands, in latitude 32° N. Oysters thrive on the south side of Cape Cod, but are practically absent from the colder waters north of the Cape.

In many ways the life of the sea is in strong contrast with that of the land. Thus most familiar land plants are fixed in position, but many sea plants float. Most land animals are free to move about, while many of those in the sea, such as polyps and barnacles, are fixed through most of their lives. Many which are not fixed move about but little, either lying on the bottom or burrowing into it. Some, on the other hand, as many of those in the surface waters (*pelagic life*), appear to be moving always.

All the great groups of animal life are represented in the sea. Even warm-blooded mammals (whales, seals, walruses, etc.) abound in frigid waters, among icebergs and ice-floes. Some of them, like the seals and walruses, do not spend all their time in the water, but frequently crawl up on the ice or land. The varieties of plant life are many, but the forms we are most familiar with on land are wanting.

Not only are there many varieties of marine plants and animals, but the largest modern animals (*whales*) live in the sea. Many sea

plants, too, are of great size. Some sea-weeds are six inches in diameter, and some have a length greater than that of the tallest trees. They are, however, not so bulky as large trees, and the amount of solid matter which the largest sea-weed contains is far less than that of the largest tree. This would be seen if the large sea-weeds were allowed to dry.

The life of the sea is important in many ways. Fish, oysters, clams, crabs, lobsters, etc., are used for food (p. 561). The total value of food products derived from the sea probably is not less than $500,000,000 per year. The best fishing regions are found where large areas of shallow water (as over broad continental shelves) furnish extensive feeding and breeding grounds for vast numbers of fish. The most important region of this sort is the shallow water about the British Isles, including the North Sea. The British fisheries alone employ more than 100,000 men, and yield an annual catch valued at more than $50,000,000. Similar conditions led to the development of important fisheries from New England, especially from Massachusetts and Maine (p. 562).

Other animals furnish other articles of commerce. For example, the seal furnishes fur and oil; the whale, oil and whalebone; and the hide of the walrus makes exceptionally strong leather. Coral and sponges, products of animal life, are also articles of commerce. The supply of lime for fertilizer, as well as for plaster, mortar, cement, and concrete, comes chiefly from limestone, most of which is composed of the secretions of sea animals. Sea-weed was used formerly as the chief source of soda and of iodine. Some varieties still are gathered in large quantities on the coast of Massachusetts and Europe, to be used as food under the name of "Irish moss."

Coral reefs. The little *polyps* (Fig. 133) which secrete coral live where the water (1) is 120 feet or less in depth, (2) is never colder than about 68° F., (3) has the saltness of normal sea-water, (4) is nearly free from sediment, and (5) is subject to some movement by the wind. Where these conditions exist, polyps thrive and make reefs, and the reefs may become islands. Polyps flourish along the borders of many tropical lands, and in some places far from shore.

Coral reefs are of several classes. Those which are separated from the land by a somewhat deep channel or lagoon are *barrier reefs*. Those close to the land are *fringing reefs*. Rudely circular reefs inclosing a central lagoon are *atolls*. The chief importance of coral reefs is their relation to navigation. Atolls frequently afford shelter

to vessels in distress, far from the mainland. Submerged reefs, however, are dangerous, and long barrier reefs may hamper commerce seriously. Thus the Great Barrier Reef extends along the east coast of Australia for 1,000 miles. It is broken by many inlets, but only a few of them allow the passage of vessels. Within the reef the water is calm and favorable for steamships, but dangerous for sailing

Fig. 133. Coral formations, Samoa. (Muir and Moodie.)

vessels, which are affected more by the winds. Partly because of the reef, no important port is found along this part of the coast.

The use of pink or red coral for jewelry leads to important coral "fishing" in the Mediterranean, whence much of the product goes to India.

Most of the natives of coral islands are backward in civilization, because of the limitation of their resources.

Questions

1. Why is agriculture possible on a limited scale in Alaska, and not in the same latitudes in Labrador, Greenland, and Baffin Land?

2. Why is Alaska less favorable for agriculture than Norway?

3. Why is the climate in latitude 50°, on the west coast of South America, less favorable for farming than that in latitude 50° on the west coast of North America?

4. Why are isotherms affected less by ocean currents in the southern hemisphere than in the northern?

5. On which side of the Gulf Stream, in latitude 45°, are fogs more common? Why?

6. Are fogs more likely to occur over a warm current, or over a cold one? Why?

7. In order to enter a shallow harbor, is a vessel more likely to have to wait for flood tide, at the time of neap tides or at the time of spring tides? Why?

8. What inference might be drawn from the fact that polyps once lived within the Arctic Circle?

9. What changes in geography are implied by the fact that polyps once lived in eastern Wisconsin?

10. How would the general conditions of climate and commerce be changed if the oceans were where the continents are, and the continents were where the oceans are?

11. Why are steamer routes across the Atlantic farther south in summer than in winter?

12. Why do several steamship routes (Fig. 113) converge at the mouths of many large rivers?

13. Why are there so few steamship lines (Fig. 113) crossing the South Pacific and South Atlantic oceans?

14. Why is the water along the equator in the Pacific Ocean warmer toward the western border of the ocean? What does the principle involved suggest in regard to the surface temperatures in the Gulf of Mexico?

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CHAPTER XIII

THE MATERIALS OF THE LAND AND THEIR USES

General Constitution

The mantle rock. Loose material such as clay, sand, and gravel, covers most of the land. This cover ranges in thickness from a few inches to scores or even hundreds of feet, and is called *mantle rock*, because it forms a mantle over the underlying rock, which in most places is solid. Mantle rock, which is formed by the decay and breaking up of solid rock, is called also *rock waste*.

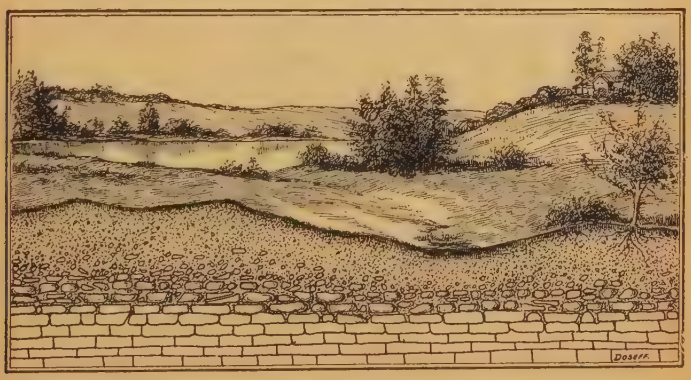

Fig. 134. Diagram showing transition from residual soil into the solid rock beneath.

The uppermost part of the mantle rock, which serves as a source of food for plants, is called *soil*. It varies in thickness from two or three inches to as many feet. Locally, it is much thicker. Soil consists of small particles of minerals, usually mixed with partly decayed vegetable matter (*humus*). Both mineral and organic matter are necessary parts of a good soil, but their proportions vary greatly. The former is the more abundant in most cases. In color, soil may

be yellow, dull red, gray, brown, or even black when much humus is present. It may be either clayey and compact, or sandy and porous.

In order to support plant life, soil must contain both air and water. Air always is present in sufficient amount, unless crowded out by

Fig. 135. Igneous rock; the upper Yosemite Falls.

excess of water, as in the case of certain swamp soils. On the other hand, the necessary amount of water may be lacking, as in deserts. Such soils are barren, even though perfect from the physical and chemical standpoints. In western United States, large areas of barren land need only water to be of great value agriculturally.

In excavations, as for cellars, wells, railway grades, and the like,

it may be seen that soil grades down in many places into material which, though loose, is different in color and texture from the soil above. This is the *subsoil*. In most places the subsoil is much thicker than the soil, though it may be absent. (How does the amount of humus in the subsoil compare with that in most soils?)

Solid rock. Beneath the subsoil is solid rock (Fig. 134), which extends down to the lowest accessible depths, and doubtless far beyond, probably even to the center of the earth.

Fig. 136. Stratified rocks; bank of Wisconsin River, below Kilbourn.

Classes of solid rock. Rocks differ in many ways. Their particles are of different kinds, sizes, and shapes. Some rocks are cemented slightly, others firmly. Some are arranged in layers, others are not. Since these and other differences are largely the result of the different ways in which the rocks were formed, they have been classified on the basis of origin. (1) Rocks formed by the solidification of lavas are *igneous rocks* (Fig. 135), of which granite is an example. (2) Rocks formed by the consolidation of sediments are *sedimentary rocks*. Since in most cases the latter are arranged in layers or *strata*, they are called also *stratified rocks* (Fig. 136). *Conglomerate* (cemented gravel), *sandstone* (cemented sand), *shale* (solidified clay), and *limestone* (in most cases the cemented remains of the shells or other secretions of animals) are the common sedimentary rocks. (3) When

the character of an igneous or sedimentary rock is changed greatly, it becomes a *metamorphic rock* (Fig. 137; metamorphic = changed).

In interior United States, solid rocks may be seen chiefly in quarries, mines, along the courses of certain rivers, and in a few other situations; but in eastern Canada, in western Scandinavia, among high

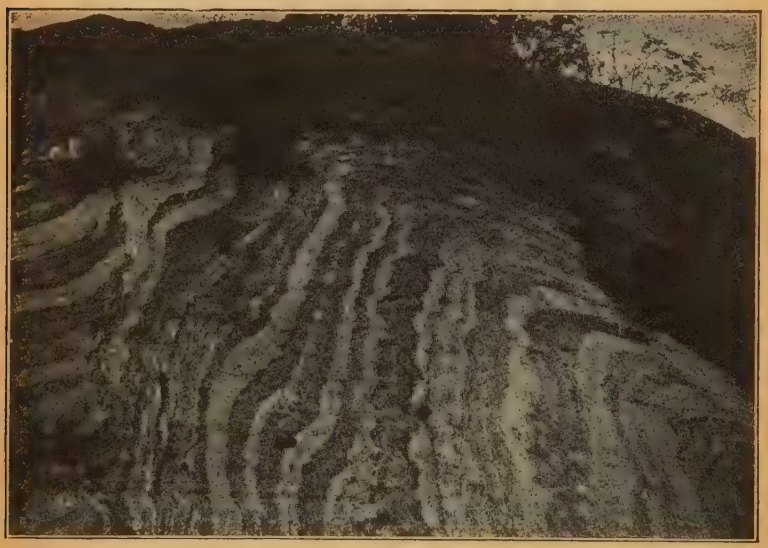

Fig. 137. Metamorphic rock. (Ells, Can. Geol. Surv.)

mountains generally, and in many other places, they come to the surface over large areas. Such places have little value from the standpoint of agriculture, even though other conditions are favorable.

Soils

Importance to man. Man depends, directly or indirectly, on soil for most of that which he eats and wears. Products of the soil furnish the principal articles of commerce, and its cultivation constitutes the chief basis of civilization. These relations, too, are lasting ones. Whether the United States shall in the future contain a numerous, well-to-do, progressive population, or a sparse, under-fed, and non-progressive one, is largely a question of whether the soil of

the country is maintained in amount and fertility. In 1900, 35.7 per cent of the wage earners of the United States were employed in farming.

The Making of Soils

We have seen that most soils are formed by the decay and breaking up of solid rocks. All changes which make solid rock crumble are processes of *weathering*. The weathering of rock prepares it for transportation by wind and water.

Chemical processes. The oxygen, carbon dioxide, and water vapor of the atmosphere are active *chemically*. The meaning of chemical action is illustrated by the rusting of iron. Iron rust is composed of iron, oxygen, and water. Oxygen and water from the air enter into chemical combination with the iron. While all three of these substances are in the rust, the rust does not look or in any way seem like any one of them. The union of oxygen with any other substance, as iron, is *oxidation*. The union of water with another substance is *hydration*. Iron rust is therefore *oxidized and hydrated iron*.

The union of oxygen and water with iron increases its volume, and the pressure which results causes crumbling. If rusting is allowed to continue, the iron is soon "eaten away" entirely; that is, it crumbles to pieces. In this case, as in many others, *chemical change* produces physical change. Because it is "eaten away" (weathered) by rusting, it is important to keep iron, such as that used in bridges, fences, cars, etc., protected by paint. All igneous and most metamorphic rocks contain iron which may be oxidized and hydrated. When these rocks are exposed to the air, therefore, the iron in them is changed (rusted), and this tends to make the rock crumble. Other chemical changes tend to produce the same result. Iron is present in all soils, and the yellowish red color of many soils and subsoils is due to the oxidized and hydrated condition of their iron. Some of the substances made by chemical changes in the rocks are soluble, and if they are dissolved and carried away by waters passing through the rock, their subtraction makes the latter more porous, and thereby weakens it. Some rock-making minerals are soluble without chemical change, so that solution is one of the most important means by which rocks are made to crumble, and by which soils are formed.

Mechanical processes. (1) When water freezes, it expands about one-tenth of its volume, and in doing so exerts great force. When it freezes in rock cavities which it nearly fills, it acts like a wedge,

and may pry the rock apart and break off pieces. This process of rock-breaking is most important when there is abundant moisture, and where the changes of temperature above and below the freezing point of water are frequent. (In what latitudes is the process most important? At what altitudes near the equator?)

(2) When solid rock has no covering of loose material, as on many steep slopes, it is heated by day and cooled by night. At high altitudes, and especially on slopes and cliffs exposed to the noonday sun, the daily changes in the temperature of the surface of the rock are great. Rocks expand when heated and contract when cooled. Since they are poor conductors of heat, it is their surfaces which are affected first, and most, by changes in temperature. Under the daily heating and cooling, the surface part of the rock breaks and scales off (Fig. 138). The breaking of cold glass when touched with hot water, or of hot glass when touched with cold water, involves the same principle. The shattering of rock by heating and cooling is very common, particularly in high mountains. Thus the upper part of many a mountain is covered with broken rock, so insecure that a step may loosen many pieces and start them down the mountain (Fig. 139). Great piles of such debris (called *talus*) bury the bases of some mountains to the depth of hundreds of feet (Fig. 140). Pieces of talus range from tiny bits to masses weighing tons. They tend to decay, gradually forming soil, after which, if other conditions are favorable, the slope is occupied by plant life. Changes in temperature not only break rocks directly, but also increase greatly the surface exposed to chemical action.

Fig. 138. Surface of bowlder scaling off under changes in temperature. (Taff, U. S. Geol. Surv.)

(3) The growth of roots in cracks in the rocks enlarges the openings, and so helps to break the rocks (Fig. 141).

(4) Burrowing animals make openings in the ground, and in the aggregate bring large quantities of loose material to the surface, where it is exposed to wind and water.

(5) Rivers wear the bottoms and sides of their channels, and so help reduce solid rocks to fine material.

(6) Glaciers grind and crush masses of rock into such fine material that some of it is called "rock flour." Much of the mantle rock of northeastern United States was ground up by ancient glaciers (p. 387).

Fig. 139. Summit of Granite Peak, Wasatch Mountains, showing broken character of the rock. (Church.)

(7) In many dry regions, wind-driven sand wears exposed rock surfaces and forms large quantities of fine, loose material.

Fig. 140. View showing long talus slopes. (Russell, U. S. Geol. Surv.)

Classes of Soils

In the paragraphs which follow, the term soil is used to include the subsoil also, where the distinction between them is not important.

Soil which remains above the solid rock from which it was formed is *residual soil* (Fig. 134). On the other hand, *transported soil* has been brought from its place of origin to its present position by some of the agents (wind, water, or ice) which transport materials on the surface of the earth. In general, transported soils are richer than residual soils (Why?), though this is not always the case.

Fig. 141. A tree growing in a crack in the rock. The growth of the tree widens the crack. Sierra Nevada Mountains, California.

Residual soils. Any kind of rock may decay, and the decayed rock, properly weathered, becomes soil. Soils derived from igneous and metamorphic rocks are in many places relatively infertile. In some cases they are unproductive because they are on lands which are high (plateau or mountain) and rough. On the other hand, the soils of the rich cotton lands of India are said to be formed by the decay of igneous rocks, and the soils of some of the best wheat lands of the Pacific Northwest have been described in the same way. In the latter region, however, the rich soils are in part, at least, of loess (p. 265), not of decayed igneous rock. Among stratified rocks, most sandstones weather into poor soil. Shales produce clay soils of greater average fertility, but in some cases they are heavy, and hard to work. Limestone soils are, as a class, very fertile, but if their limey constituents are dissolved out, as they may be, the soil is less fertile. Stratified rocks form some high plateaus (as in Arizona) and mountains (e. g., the Appalachians), but they are the commonest rocks beneath plains, and over great areas the soils derived from them are on level areas or gentle slopes favorable for cultivation.

Transported soils. Transported soils are much less uniform in composition and texture than residual soils. In many cases they represent material gathered from a large area, and are entirely unlike the rocks on which they rest. Sediment transported and deposited

by rivers is *alluvium*, and soils developed on alluvium are *alluvial soils*. Such soils in the flood-plains and deltas of great rivers, when not too wet, are commonly of great fertility. The rich soil of the great *alluvial fan* (p. 361) of the Hwang-ho, in China, supports one of the densest populations in the world. Ancient civilizations were confined so generally to rich flood-plain soils that the period before 800 B. C. has been called the *Fluvial Period*.

Eolian soils are formed from sand or silt deposited by the wind. Eolian deposits cover large areas in various regions (p. 315), but while the sand is loose, and being blown about, it is hardly soil and offers little chance for agriculture. For this reason, part of an extensive area of sand-hills in western Nebraska has been set aside for a National Forest. It is believed that certain trees which can get along with little moisture may be grown here successfully, and that the entire sand area may be covered finally with a profitable forest. Large areas of land have been reclaimed in this way in the southwestern part of France.

Wind has been concerned in the deposition of *loess* in certain regions. Loess is a loam, of buff or gray color, coarser than clay, and finer than sand. Soils formed from loess are very fertile when well watered. In parts of China, loess deposits have a thickness of several hundred feet. Some of the best farming lands of the Rhine, Danube, and other European river basins have loess soils. In our country, such soils occur in some parts of the Mississippi Basin, particularly along parts of the Mississippi and Missouri rivers. Before the Civil War, the counties of Missouri covered with loess contained a larger percentage of slaves than most of the rest, and grew large quantities of tobacco. The loess-covered counties of eastern and southeastern Nebraska produce most of the corn, wheat, oats, and alfalfa grown in the state. They are settled more thickly, and have more improvements, than most of the rest of the state.

Much of the mantle rock of Canada, northern United States, and northern Europe, was brought to its present position by the great ice-sheets which once covered the region (p. 387). This material is called *drift*. Soil formed from drift varies much in character and fertility. Some of it is too sandy and some is too stony, but much of it is of excellent quality. Since the glacial drift was made not very long ago (as geology reckons time) by the grinding up of rocks of many kinds, the soils made from it are likely to contain all the mineral elements essential for plant food.

Formation versus Removal

Relation of gain and loss. It has been estimated that in the United States it may take, on the average, 10,000 years to form a foot of residual soil (833 years for an inch). Slow as this rate is, it is faster than the average rate at which soil is removed by surface waters, winds, etc. If soil were removed faster than it is formed, the land would in time be without soil, as it is now in some places, espe-

Fig. 142. View in the Apennine Mountains, near Florence. Shows the shallow, stony soil which remains after the loam has been washed away. By removing the slight protective cover of vegetation, the sheep promote further erosion. (Sketch from photograph by Willis.)

cially on steep slopes. With the clearing away of forests and the plowing of land for agriculture, the rate of soil erosion was increased greatly, and it now exceeds the rate of soil formation over large areas. From parts of the Apennine Mountains (Fig. 142), Dalmatia, Palestine, and China (Fig. 143), where the land had been cultivated for centuries, the soil has been washed away, and the land is now barren. This shows what must be expected in some parts of this country, if soil erosion is not checked. The Mississippi River carries, on the average, more than 1,000,000 tons of the richest soil matter per day into the Gulf of Mexico. The work performed each year by the Missouri River in transporting material toward the sea is estimated to be equivalent to 275,000,000,000 ton-miles (a ton-mile is a ton carried a mile). All the railroads of the United States carried 236,600,000,000

ton-miles of freight in 1907. The annual loss to the country from the washing and leaching of soils is estimated at some $500,000,000. Although the land even of eastern United States has been cultivated but a short time compared with that of Europe, yet nearly 11,000,000 acres once farmed have been abandoned. More than one-third of this area has been ruined for farming by the erosion of the soil. It

Fig. 143. View in the western part of the province of Chi-li, China. The erosion of the metamorphic rocks has been aided in places by recent deforestation. (Willis, Carnegie Institution.)

has been estimated that the area thus ruined would, if covered by fertile soil, be capable of supporting a population greater than that of any one of the twelve least populous states. Doubtless the total loss to the country from the *partial* destruction of soil is even greater. Nor is this all. (1) The soil carried away may do much harm where it is deposited (Fig. 144). (2) Streams which carry much sediment deposit some of it in their channels, thus impeding navigation. (3) The clogging of river channels also helps to cause floods. (4) Reservoirs, such as mill-ponds, may be filled with sediment, interfering with manufacturing. (5) Streams are polluted, interfering seriously with their use as a source of water supply for cities, and compelling the maintenance of expensive filtering plants.

Factors controlling soil erosion. Several factors influence the rate of soil erosion. (1) It is greater on steep slopes than on gentle ones. Lands in the southern Appalachians have been cleared of forests and cultivated, where the slopes are so steep that the soil was

Fig. 144. Land covered with sand. The river has deposited a bed of sand on the former flood-plain surface, converting it into a barren sand waste. (Glenn, U. S. Geol. Surv.)

washed away in eight or ten years, and the land abandoned. (2) It varies with the amount and distribution of rainfall. The more the rainfall and the more rapidly it falls, the more rapid the erosion of the soil. The greatest storm of a year may wash away more soil than all the other rains of that year. (3) It is influenced by the presence or absence of vegetation, and in the case of cultivated land by the kind of crop. Bare soils, and those devoted to widely-spaced plants, wash faster than grass lands and forest lands. (4) It is affected by the texture of the mantle rock and solid rock. (Which would favor greater wash, compact or porous soil? Compact or porous material below the soil?)

Fig. 145. Terracing in western North Carolina. (Sketch from photograph by N. C. Geol. Surv.)

Prevention of soil erosion. There are various ways of reducing soil erosion. The more important are the following: (1) Deep and

frequent tillage increases the power of the soil to absorb rain, and so reduces the amount of water running directly off over the surface. This is highly desirable apart from its effect on erosion, for few places have water enough to produce maximum crops. (2) Plowing and planting along contours produce little depressions and ridges at right angles to the slope. These tend to check erosion (How?). Plowing up and down a slope, on the other hand, increases erosion (Why?). (3) On steep slopes, wash may be reduced by making a series of terraces or benches. Terracing is practiced in parts of the Piedmont Plateau (Fig. 145) and elsewhere in the South, and in many countries of Europe and Asia (p. 475). (4) The soil should be kept covered with vegetation as much as possible throughout the year. (5) Grasses tend to prevent wash in several ways (How? Fig. 146). (6) On slopes exceeding 18° or 20° in steepness, the soil is protected best by trees (Fig. 147), and, in general, such land should be devoted to forests. The restraint and prevention of soil erosion are among the most important problems of the conservation movement, and they depend very largely on individual land-owners.

Fig. 146. Erosion as result of killing of grass by stock. Foothills of Sierra Nevada Mountains, California. (Fairbanks.)

Fig. 147. View showing effect of roots in holding soil. San Juan Mountains, Colorado, near Silverton. (Fairbanks.)

Mineral Plant Foods

Proper care of the soil requires not only the prevention of erosion, so far as possible, but also the keeping in the soil of the mineral matters needful for plant food. The elements essential to plant life are phosphorus, potassium, calcium, silicon, carbon, hydrogen, oxygen, and nitrogen. Several of these elements are derived wholly from the soil and from the water in the soil, while others are taken from the air. A number of other elements derived from the soil, such as sulphur, sodium, and iron, are also used in minute quantities by plants. Different crops draw unequally on the mineral foods of the soil, and when one crop is grown on the same ground year after year, the soil becomes poor in one or more of these foods, and its productivity is reduced. The almost exclusive cultivation of tobacco injured the soil in parts of colonial Virginia. This helped to send thousands of farmers west of the Appalachian Mountains in search of new land. Southern Wisconsin was primarily a wheat region from the 1830's to the 1870's, when the diminishing yields and the competition of the new, rich soils farther northwest forced the cultivation of other crops, and the adoption of better methods of farming. Where crops of different kinds are raised, one after another (rotation of crops), the soil remains in better condition; but unless the essential elements taken from the soil by plants are returned in some way, its fertility must diminish. "Worn-out" farms are common in the South and East, and even in parts of the Upper Mississippi Basin. Land may be kept from wearing out by giving it the elements it lacks, that is by *fertilizing* it. In some parts of the southeastern states, where the soil was made poor by the long-continued growth of cotton or tobacco, no crops are grown without the use of fertilizers.

Natural processes tend to add to the soil the chemical substances essential to plants. New soil is formed by the weathering of underlying rocks (p. 261), and ground-waters bring mineral matter in solution from below, which they may deposit near the surface, enriching the soil. In most cases, these processes of soil renewal and enrichment fail to offset the drain upon the soil imposed by ordinary methods of agriculture. While in many places natural processes tend to enrich soils, surface and underground waters may also erode (p. 266) and leach soils, thereby reducing them in amount and productivity.

Except phosphorus, the supplies of the elements which plants need are abundant from one source or another. Hydrogen and oxygen are the constituents of water, and oxygen makes one-fifth of the

atmosphere. Next to oxygen, silicon is the most abundant element in the earth's crust. Most rocks contain a little calcium, and limestone contains much. Carbon is derived from the carbon dioxide of the air, and the latter contains an unlimited supply of nitrogen which may be drawn upon by certain plants, though most plants depend on the nitrogen compounds in the soil or in fertilizers (p. 47). Potassium is a constituent of many common rocks, and, in addition, there are large deposits of potassium compounds in various places, especially Germany. The compounds of potassium are dissolved readily by ground-water, so that soils are likely to become poor in this element. Wood ashes contain potassium, and for this reason they are good for land.

Unlike the foregoing, phosphorus is a relatively rare element, and already the original amount in the soil has been diminished seriously in many parts of the United States. Guano, chiefly from islands off the west coast of South America, is an important source of supply, though little is imported into the United States. The bones of domestic animals are a second source, and the manufacture of phosphate fertilizer is an important industry at the great slaughtering centers. The bones of buffaloes, killed in great numbers years ago, have been gathered up by the train-load from the western plains and used in the same way. Enormous quantities of phosphorus are now lost in the sewage of great cities, and in the leaching of farm manure. This phosphorus should be returned to the soil, so far as possible. Some European countries are far ahead of the United States in this matter. Finally, the United States possesses the greatest known deposits of phosphate rock (rock containing much phosphorus), and because phosphorus is to be a critical factor in the fertility of soil, these deposits constitute one of the most important mineral possessions of the nation. In the Southeast, there are deposits in South Carolina, Florida, Tennessee, and Arkansas. The first three of these states furnish nearly all the phosphate rock now mined in the United States. In addition, there are far greater deposits in Idaho, Wyoming, Utah, and Montana. There is, unfortunately, much waste of the poorer phosphate rock in mining — material which, if saved, would be of great value in the future. Unfortunately for the United States, too, increasingly large amounts of phosphate are being exported.

It is not to be inferred from the above discussion that fertility of soil is determined solely by its chemical composition. The productivity of soil is influenced also by (1) its physical condition (coarseness, fineness, etc.), (2) its water content,

(3) the organic matter (humus, etc.) which it contains, (4) the minute organisms (especially bacteria) at work in it, (5) the presence of toxic bodies (the accumulated excreta of plants), and by other factors. Furthermore, the yields obtained from a given soil are affected greatly by (1) the quality of seed sown, (2) the effectiveness of cultivation, and, in many cases, by such things as (3) harmful insects, (4) plant diseases, and (5) weather conditions. The reduced yields of many long-cropped soils probably are due in part to causes other than the impoverishment of the mineral elements of plant food.

General Distribution and Use of Soils in the United States

The principal physiographic provinces of the United States are shown in Fig. 148, and the principal soil provinces in Fig. 149. Since the settlement and development of these provinces have been influ-

Fig. 148. Map showing the principal physiographic subdivisions of the United States.

enced profoundly by the configuration of the land and the character of the soil, the larger provinces may be considered briefly.

The Atlantic and Gulf Coastal Plains. The Coastal Plain widens southward from New York City, and has its greatest width in the Gulf region, whence it extends northward along the Mississippi to the mouth of the Ohio. Much of the Coastal Plain is less than 100 feet above sea-level, though some parts of it are considerably higher. The underlying rocks are imperfectly cemented gravels, sands, clays, marls, and limestones. Along the coast there are extensive marshes, where most of the soil is too wet for cultivation.

The draining of these swamps has been begun, as for example on the delta and lower flood-plain of the Mississippi, and when it is completed their rich soils will support a dense farming population (p. 460). Elsewhere, the soils of the Coastal Plain present great variety. Over the marls and limestones they are fertile, and over the sands, gravels, and clays they are much less productive. Many sandy tracts, as in parts of southern New Jersey, have remained wooded

Fig. 149. Map showing the principal soil provinces of the United States. (After Whitney, with slight modifications.)

and sparsely settled to the present. In the Carolinas such belts, called "barrens," long helped to separate the life of the tidewater country from that of the Piedmont Plateau. In contrast with the sandy areas, the bottom lands of the rivers, where not too wet, and the belts of limestone soils are the garden spots of the South. Here most cotton was grown before the Civil War, and most slaves were owned (p. 492). Here the negro population is densest to-day. It is probably true that the rich soils of many parts of the Coastal Plain, and the genial climate of the South, were responsible for the continuance of slavery in the United States to the time of the Civil War.

The New England Hills. There is no continuous Coastal Plain in New England. The most important lowlands have developed on weak rocks in the Connecticut Valley, about Narragansett Bay, and

around Boston. On these lowlands the early history of Connecticut, Rhode Island, and Massachusetts centered. To-day, the Boston Basin contains about half the people of Massachusetts, and one-fourth those of all New England. Apart from these lowlands, most of New England is hilly. Much of its glacial soil is thin and poor, and in many places stony (Fig. 150). It has been estimated that in some parts it took, on the average, one month for a man to remove the stones from each acre of glacial drift, to get it ready for farming. Many of the early settlements were made in areas of stratified drift (p. 407), where the bowlders were fewer and the land flatter.

The unfavorable soils and the harsh climate prevented a high development of agriculture in New England, which was without a

Fig. 150. A bowlder-strewn surface in Maine.

single staple crop for export, such as colonial Virginia had in tobacco, and South Carolina in rice and indigo. By the close of the seventeenth century, more than half the people of New England were engaged in industries other than agriculture, and it is said also that more than half the time of the farmers was given to non-agricultural work. For two centuries the life of New England was dominated by industries centering in the ocean,—chiefly fishing, shipbuilding, and the carrying trade. Later, manufacturing became the leading interest.

Crude methods of agriculture in early days led to the exhaustion or partial exhaustion of such lands as were originally good for farming. When the lands ceased to produce good crops they were deserted, and much has been written and said of the abandoned farms of New England. But in recent years many of these farms have been brought under cultivation again, and with the improved methods of to-day they are producing satisfactory returns. It seems certain

that many of the abandoned farms here will be reclaimed. Much of the rough, infertile upland of New England, however, probably can be used to best advantage in the future for forests.

The Piedmont Plateau. The Piedmont Plateau has an elevation varying from 250 or 300 feet at its eastern edge, to about 1,000 feet in places along its western margin. It is underlain for the most part by crystalline (metamorphic and igneous, p. 259) rocks. The higher lands have a rather poor, residual soil, but many of the valleys have rich, alluvial bottoms.

The Appalachian Mountains. The Appalachian Mountains consist of both sedimentary and crystalline rocks. The soils of the larger valleys are fairly fertile. This was strikingly true, originally, of the limestone soils of the Great Appalachian Valley, which, under various names, extends from Georgia to New York. This great valley was one of the first areas west of the Blue Ridge to be settled, and it soon became an important grain-producing section. During the Civil War, the Confederate armies drew large quantities of supplies from its fertile fields.

The upper slopes of the mountains are steep, and covered with poor soil which washes easily when the forest is removed. A National Forest is to be established in the southern Appalachians, and the steeper land devoted permanently to forestry. In the future, the country must look to the Appalachian forests for much of its supply of hardwood.

The Cumberland-Alleghany Plateau. The surface of this plateau is much dissected by valleys cut in the nearly horizontal, stratified rocks. In general, relatively level land and fertile soil are found only in the valley bottoms. The hills have steep slopes, and their soils are infertile. Except where mineral resources have attracted settlers, the plateau is sparsely settled.

Lake and Prairie Plains. Most of this area is underlain by sedimentary rock, much of which is limestone. Most of the surface is covered with glacial soil (Fig. 149), the composition of which is influenced greatly by the nature of the underlying rocks. Thus in Michigan and Wisconsin there are extensive areas of sandy drift over sandstone, where attempts at farming, following the removal of the pine forests, have met with little success. There are also hilly belts (*moraines*, p. 395) in the northern part of the area, where the stony soil is used largely for woodlots and pasturage. There is also much marsh land, unfit for agriculture until drained. In general,

however, the soils of this region, especially the prairie soils between the Missouri and Ohio rivers on the south and southwest, and the Great Lakes on the north, are of great fertility. No other equal area in the United States is so important agriculturally (Fig. 402). Iowa, Illinois, Ohio, and Indiana are, in the order named, the first four states in the percentage of improved land to total area.

The prairies generally were avoided by the first settlers, who regarded the absence of trees as evidence of poor soil. Even after their fertility was known, the larger prairies were not settled far back from the main streams until the building of railroads provided means of transportation.

The Great Plains. The surface of this province rises from an elevation of about 1,000 feet at the east, to more than 5,000 feet at the west. Most of the region is underlain by sedimentary rocks, and, in general, has a deep and rich soil. At the north, the soil is of glacial origin (Fig. 149); farther south it is (1) partly alluvial, having been spread widely by depositing rivers flowing eastward from the Rocky Mountains, (2) partly residual, and (3) considerable areas in the eastern part of the tract are covered with loess (p. 265). The eastern part of the area is very productive, but in the western part the rainfall is too scanty for ordinary farming. Here agriculture must depend on (1) irrigation, which is possible over small areas, (2) "dry farming" (p. 498), and (3) the cultivation of drought-resisting plants, such as durum wheat and kaffir corn. Over large areas grazing probably will continue to be the dominant interest (p. 498).

The Rocky Mountains and Western Plateaus. In the different parts of this great region all kinds of rocks are found, in all sorts of positions. The soils vary as greatly as the rocks, both in origin and composition. Glacial soils are found at the north, and throughout the region in many mountain valleys. Great areas of alluvial soil fringe the bases of many of the mountains, where withering streams from the uplands have deposited their sediment. Some of these deposits have a thickness of hundreds and even thousands of feet. The steep slopes are flanked also by great piles of talus (p. 262), most of which do not support much plant life. Where the mountain slopes are not too steep, there are residual soils, and these also cover great areas of the plateaus.

Over most of the region, systematic tillage of the soil has not been possible because of (1) too great height, (2) the steepness of the slopes, or (3) lack of adequate rain. Most of the land is therefore best suited

to grazing, and, especially in the mountains, to forestry. Irrigation is making agriculture of a high order possible in many rather small areas (p. 449), especially in valleys and on other lowlands. In some such places, there is a dense population. Nowhere else in the world is fruit-raising carried on more intelligently or with better results,

Fig. 151. Relief map of California. The state is largely mountainous, but the central plain is conspicuous.

and probably nowhere else in the world has farm land sold at such high prices. Small, choice orchards have been sold at $4,000 and $5,000 per acre, and prices half as high are not rare.

The Pacific Ranges. The Sierra Nevada and Cascade ranges on the east, and the coast ranges, at the west, are composed largely, but by no means wholly, of crystalline rocks. As farther east, the soils of the mountain slopes can be used best for forests, for which, except at the south, there is sufficient rain. Among the mountains there are many fertile valleys with glacial or alluvial soils, and

between the ranges are the great waste-filled valleys of the Willamette River and of central California (Fig. 151). The rich, alluvial soils of the latter probably have given the state larger returns than its gold mines. In the southern part of the province, the value of even the best soil depends on irrigation, and unfortunately there is water enough to irrigate only about one-tenth of the land. Irrigated land, with groves of oranges or lemons, sells for very high prices, while non-irrigable land may in many places be bought for a trifle. Toward the north, with increase of rainfall, and with lower temperatures, the necessity of irrigation is less. The Willamette, Rogue, and Hood river valleys of Oregon, as well as extensive tracts in Washington, yield good crops without irrigation. But even here irrigation increases the returns from the land.

Fig. 152 shows, in a general way, the best use to which it is thought the land throughout North America may be put, and serves to illustrate many of the larger points stated in the preceding paragraphs.

Mineral Products and Their Uses

Building Stones and Clay

Building stones. The principal building stones are granite, limestone, marble, slate, and sandstone, though not all rocks of these kinds are useful for building. The strength of the rock, its color, ease of splitting and dressing, and durability all enter into the problem. Not all good stone is available, for much is too far from a market.

Granite is distributed widely in the United States. Granite and other similar rocks form the cores of many mountains, especially in the West, and are the surface rocks over large areas in the Piedmont and New England plateaus, and in the vicinity of the upper Great Lakes. Granite has been quarried in a large way for many years in New England, and more than two-thirds of all granite quarried in the country comes from the Atlantic States (Why?).

Limestone is quarried in many states, largely for local use. From a few famous quarries, such as those at Bedford, Indiana, it is shipped to all parts of the United States. Much limestone is burned for lime, and much is used for mortar, cement, railroad ballast, etc. In the making of cement, lime is mixed with clay. The recent development of the cement industry has been remarkably rapid. In 1890, the United States produced less than 350,000 barrels of Portland cement; in 1910, more than 76,500,000 barrels.

Much *marble* (metamorphic limestone) is used as an ornamental building stone. It is white if formed from pure limestone, but because of impurities may be of any color. Carbon and other impurities often form streaks or bands of varying color, producing beau-

Fig. 152. Map showing the best use to which it is thought the land throughout North America may be put. (Zon, U. S. Forest Service.)

tiful and odd effects on polished surfaces. Marble is quarried on a large scale only in the East. Vermont supplies about four-fifths of all the marble used in the United States for ornamental work, but Colorado promises to become a great producer.

Slates are metamorphic rocks formed from shale by great pressure. They are used chiefly as roofing material, but also for various other purposes. The production of slate, like that of marble, is confined largely to the East, and is most important in Pennsylvania, Vermont, and New York.

Sandstone is used for buildings, bridges, and other purposes. It is distributed widely in many states, so that numerous small quarries serve local needs. A few popular kinds of sandstone, such as the brownstone from Pennsylvania and the vicinity of New York City, have wider markets.

Gypsum is used extensively for building plaster and certain cements. It is also used as a land fertilizer, and in other ways. Great deposits of it occur in some states.

Clays and clay products. Clays have a wider distribution than most other economic rock materials, and are used in making many things. Among these are pottery of various grades, tiles, terra cotta, brick, and Portland cement (made from a mixture of clay and lime rock). Every state produces clay products, Ohio, Pennsylvania, New Jersey, and Illinois leading in the order named. The total value of the products of the clay-working industries of the country exceeded $170,000,000 in 1910.

Substitution of mineral products for wood products. Brick, stone, and cement are being substituted more and more for wood in building operations. This is highly desirable, because these materials are (1) more durable, (2) less liable to fire, and (3) their use lessens the drain on the forests. Wood was used in only 27.5 per cent (by cost) of the building operations in the 128 leading cities of the United States in 1909. Operations on brick buildings constituted 61.49 per cent of the entire cost. On the other hand, wood continues to be used much more than other materials in most of the smaller towns and villages, and in the country.

Mineral Fuels

Coal. After soil, coal is the most important of the mineral resources. Together with iron, which is next in importance, it has made possible the extraordinary industrial development of the

United States. Germany and England also have become great manufacturing nations, largely because of their extensive deposits of coal and iron. The United States has more and better coal than any other country, so far as now known. Fig. 153 shows the general distribution of its coal fields. Their combined area is about 500,000 square miles, or about 16 per cent of the area of the country. They are distributed widely, a matter of great importance, since the cost of

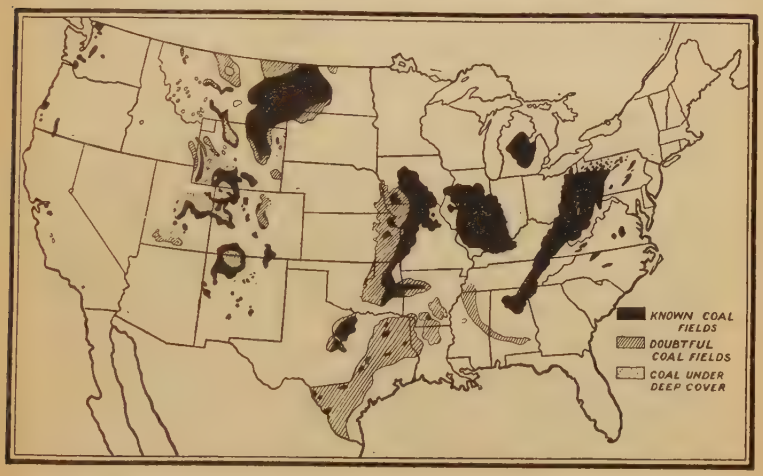

Fig. 153. Map showing general distribution of coal fields in the United States. (U. S. Geol. Surv.)

coal is largely the cost of transportation. The total amount of coal in the United States at the beginning of 1908 was estimated at more than 3,076,200,000,000 tons. About one-third of this, however, is accessible only with difficulty, and by no means all of it is of good quality. It is estimated that more than 99 per cent of the original supply of coal in the United States is still in the ground.

The mining of coal in the United States began to be important about the middle of the last century, and the output has nearly doubled each decade since. The 501,000,000 tons mined in 1910 constituted about 1/16 of all mined to the end of that year. If the output should continue to increase at the same rate, the entire known supply would be exhausted in less than 150 years. For various

reasons, however, our supply of coal will last much longer than this. Nevertheless, it is highly desirable (1) to avoid, so far as possible, the waste of coal; (2) to substitute water power for steam power (generated by the burning of coal) wherever practicable; and (3) to use coal in the most efficient way possible. The waste in mining coal has amounted to about 50 per cent of the quantity produced; that is, about 250,000,000 tons were wasted in this way in 1910. This is more coal than was mined in the United Kingdom (the second coal-

Fig. 154. Digging peat in Ireland.

producing country) in 1905. Much unburned coal passes off as smoke (p. 51). The average steam engine does not develop into power more than 6 to 10 per cent of the heat energy of the coal. In making light from coal, only a small part of one per cent of the energy of the coal is utilized. Much of this waste can be avoided, and some progress in this direction has been made already. One effect of the burning of large quantities of coal is to increase rapidly the amount of CO_2 in the air (p. 48). Indeed, it has been estimated that the amount may be doubled in this way in the next 1,500 years. It will be remembered (p. 50) that this probably would make the climate much milder.

Pennsylvania, West Virginia, Illinois, and Ohio lead in mining coal. They have produced about ¾ of all the coal mined in the United States.

Peat. Though not a mineral fuel, peat is best mentioned in connection with coal. Peat is a swamp deposit, much of it resulting from the partial decay of a moss called *sphagnum*. In the United States more than 11,000 square miles, outside of Alaska, are estimated to have peat beds of good quality, containing a total of nearly 13,000,000,000 tons of fuel when dried. The largest deposits are in the glaciated area (Fig. 273), along the Atlantic and Gulf coasts, in the Mississippi delta, and along the flood-plains of the Mississippi and certain of its larger tributaries. These great peat deposits scarcely have been touched, but the extensive use of peat in northern Europe suggests its future importance here. There it has been used for many years as fuel (Fig. 154), especially in Ireland, and recently in a variety of other ways, such as for making coke, charcoal, illuminating gas, fertilizers, and paper.

Fig. 155. Map showing general distribution of petroleum and natural gas fields of United States. (Day, U. S. Geol. Surv.)

Petroleum. The distribution of the known supplies of petroleum is shown in Fig. 155.

Petroleum was discovered in large quantities in western Pennsylvania in 1859. The field which includes this original area extends from New York to Tennessee, and has produced more petroleum than any other. The output is now decreasing, however. Most of the

petroleum of this field is of high grade. The large Ohio-Indiana field was the second to come into use (about 1885). Most of the others are of recent development. In 1910, California produced most petroleum, and Oklahoma and Illinois ranked second and third. The total output of the country was more than 200,000,000 barrels. Since 1860, as much petroleum has been produced each nine years as in all preceding years, and should this rate continue, the supply, so far as it can be estimated in known fields, would be exhausted by about 1935. Should the present output continue without increase, the calculated supply will last until about the year 2000.

Crude oil is used for fuel, for the prevention of dust on roads, and for some other purposes. From it various oils are manufactured for lighting and lubricating purposes, and many by-products are obtained. In view of the probable early exhaustion of the supply, petroleum should be used only for those purposes for which it is best adapted. Its most essential use is for the making of oils for lubricating the bearings of all kinds of machinery. For this purpose, no satisfactory substitute is known. On the other hand, the use of petroleum as fuel in locomotives and for the development of power in factories is in general unnecessary, and should be discouraged.

Natural gas. Natural gas is the most perfect fuel. So far as known, the United States has a greater supply than any other nation, and it occurs in more than half the states (Fig. 155). It is believed, however, that the natural gas now known will be exhausted within the next twenty-five or thirty years. In spite of this, and in spite of its great value, enormous quantities (estimated at 1,000,000,000 cubic feet daily) are allowed to escape from the ground unused. A large part of this waste can be prevented.

The opening up of new gas and oil fields has been attended invariably by a great local increase in land values, and in some cases has started a period of great industrial activity (p. 570). Where wells have failed later, a period of stagnation and decline has in some cases followed.

Metals

Iron. Some iron was mined in this country early in the colonial period. In eastern Massachusetts, for example, it was taken from certain marshes, ponds, and lakes, and used in local manufacturing. The production was unimportant, however, till 1850. Since then it has increased rapidly, so that the output during the decade ending

with 1909 amounted to 52.6 per cent of all the iron ore that has been mined in the United States.

It was estimated recently that the *available iron ore* (that usable under existing conditions) in the United States amounts to nearly 4,800,000,000 long tons (a long ton is 2,240 lbs.), and that in addition there are low grade ores, part or all of which will be useful in the future, amounting to more than 75,000,000,000 long tons. Like coal, iron

Fig. 156. Map showing general distribution of iron ore in the United States.

ore is distributed widely (Fig. 156), but by far the most important deposits of our country are in the Lake Superior region, especially in northern Michigan and Minnesota. This district contains about 73 per cent of the available ore of the United States, and about 95 per cent of the low-grade reserve. It had produced, to the end of 1910, nearly 500,000,000 long tons of iron ore — considerably more than half the total amount produced in the United States. In recent years it has furnished about 80 per cent of the entire output of the country. In 1910, the United States produced more than 56,800,000 long tons of iron ore—nearly half the world's production for the year.

If the iron ores of the United States continue to be mined at the increasing rate of the last few decades, the known deposits of high grade will all be mined in about ninety years. Several considerations, however, make it certain that the supply of ore will last much longer.

Furthermore, iron, unlike coal, can be used again and again. For example, old rails are made over into new ones or into other things. The great problem in conserving the supply of iron is therefore to use it again and again, keeping the stock as nearly intact as possible. There is little waste of iron ore in mining.

Copper. The existence of copper on the southern shore of Lake Superior (Keweenaw Point) was known to the Indians at an early date. As late as 1845, however, the entire output in the United States amounted to only 100 tons a year, and not till 1867 did copper begin to be used in large amounts. Its use has increased rapidly in recent years, and in 1910 approximately 540,000 tons were produced. Nearly three-fifths of the entire amount produced in the United States have been extracted during the last ten years. Michigan, long the leading copper state, is now out-ranked by Arizona and Montana. Some nine other states, most of them in the West, produce copper, several of them in large amounts.

Copper ores are scattered so widely, and are so irregular in their occurrence, that the supply has not been estimated accurately. It is thought, however, that the *known reserves* of copper ore, usable at existing prices, will be exhausted in Michigan in fifteeen or twenty years, and in Montana and Arizona in even less time. Should the value of copper increase, lower grade ore could be used. Even now, at the Michigan mines, only twenty-two pounds of copper are obtained, on the average, from each ton of ore. New discoveries of copper are being made from time to time. For these and other reasons, the deposits will last much longer than the time suggested above.

Copper is used chiefly for making wire and brass. Fortunately, these uses involve little unavoidable waste, so that the same copper may be used repeatedly. Some copper is used for chemical purposes.

Gold. The production of gold was unimportant in the United States until after its discovery in California in 1848. The leading gold-producing states are Colorado, California, and Nevada. Each produces about 1,000,000 ounces (an ounce is worth about $20) of gold per year. Alaska is also a heavy producer. The amount of gold which remains to be mined cannot be estimated, nor, in consequence, the duration of the deposits. It already is practicable to mine very low grade ore. In some cases, for example, a ton of ore is mined and milled to recover one-eighth of an ounce

of gold. Gold is used chiefly as coin and bullion, and in the arts. Most of its uses involve little waste or loss of the gold itself. Even were the supply used up, the loss would be much less serious than that of coal or iron.

Silver. Neither the amount nor the future life of the silver deposits of the United States can be estimated. Nevada, Montana, and Utah are (1910) the leading silver-producing states, followed by Colorado and Idaho. Like gold, silver is used chiefly for coin and in the arts. Its use in photography is an interesting and a rapidly increasing one. In general, there is little waste or loss in its use.

Lead and zinc. Lead was known to the Indians of the Mississippi Valley before the coming of the whites, but the deposits of the region were not worked effectively until the early 1820's, when a period of great activity in mining began. This culminated in Illinois and Wisconsin about 1845, and during the next few years many of the miners went to the new iron fields of Lake Superior, and to the gold fields of California. Lead was discovered later in a number of the western states, in many places in association with silver. Missouri is the leading lead-producing state, followed by Idaho and Utah.

Lead is another metal the amount and duration of which cannot be estimated accurately. The known supply is, however, very limited. Much lead is lost needlessly by the current methods of mining, milling, and smelting. About one-third of the lead produced in the United States is used in the manufacture of paint. Lead used in paint can be used but once, and more abundant things will have to be substituted for it increasingly in the future.

Zinc is associated in many places with lead, and for years was regarded as valueless by lead miners. The first zinc plants were erected in Illinois in the late 1850's, but for twenty years the production was small. In recent years it has increased very fast, and the output of the last decade equalled that of all earlier years. Missouri leads, by a large margin, in the production of zinc. There is great waste of zinc in mining, concentrating, and smelting. About two-thirds of that produced in this country is used for galvanizing iron. Like lead, it is used also for making paint. Most of the rest is used (with copper) for making brass, and for sheet zinc.

Aluminum. Aluminum is by far the most abundant of the metals. It is a constituent of all important rocks except limestone and sandstone, and makes up more than 8 per cent of the earth's

crust. It is light, strong, malleable, ductile, is a good conductor of electricity, takes and retains a high polish, and does not corrode easily. These properties fit it for many purposes, but the difficulty and expense of separating the metal from its combinations long prevented its extensive use. It is extracted on a commercial scale only from *bauxite*, a relatively scarce mineral. When it can be obtained cheaply from clay, of which it forms a part, its use will be increased enormously.

The production of aluminum in the United States increased from 83 pounds in 1883 to more than 47,000,000 pounds in 1910. It is used for making a constantly increasing variety of things, such as cooking utensils, castings, wall "paper," ceiling panels, paints, varnishes, and wire. Doubtless in the future it will replace iron, copper, and some of the other metals for many purposes.

Salt

Salt is indispensable to man, and fortunately the supply is practically inexhaustible. (1) In arid regions there are many lakes with no outlets into which streams bring minerals (including common salt) which have been dissolved during the passage of the water through or over the rocks (p. 330). These things are left behind as water evaporates from the surface of the lake, which becomes more and more saline as the process continues. When the waters of the lake become saturated, further evaporation causes the minerals to begin to be precipitated from solution. Great Salt Lake is estimated to contain some 400,000,000 tons of common salt. (2) Extensive salt beds which were laid down in ancient lakes or arms of the sea are found between beds of other rock in many places. Those in central New York may have an area underground of some 10,000 square miles (larger than Vermont), and single beds are in places 80 feet thick. Beside New York, Michigan and Kansas are leading salt-producing states. (3) The ocean constitutes the remaining and greatest source of supply (p. 235).

The need of salt helped to hold most of the American colonists near the Atlantic coast for a long time. Not until it was discovered in the Holston and Kanawha valleys (Tenn. and W. Va.), in central New York, and in Kentucky, did dependence on the coast for salt cease. In 1778, salt brought on pack animals over the Appalachian Mountains sold in southwestern Pennsylvania for £6 10s. per bushel. The same amount of salt now is worth but little more than 10 cents where it is prepared, and not more than 50 cents in the markets in most parts of the United States.

Conservation of Mineral Resources

The mineral resources noted above are a part of the heritage of the earth. The people of to-day have a right to use such of them as they need, in as great quantities as necessary. It is their duty, however, to use them in such a way as to insure the minimum of waste and the maximum of efficiency. This is demanded alike by the interests of the present generation, and by those of generations to come. The facts given show that many reforms are needed. The reckless waste of some of these resources is a reflection upon American intelligence.

Questions

1. Does the absence of soil in any given place mean that it is not in process of formation there? Explain.

2. Is the breaking of rocks by expansion and contraction most important at high or at low altitudes? In high, middle, or low latitudes? In moist or dry climates? Why?

3. What are the principal ways in which soil is being formed in New England? Florida? Nevada?

4. Why are the soils of the lower flood-plains and deltas of large rivers of great fertility in most cases? Are they commonly of coarse or fine texture? Why?

5. Enumerate the conditions (all of them) which may explain the fact that soil wash is, in some cases, much faster on one of two equal slopes than on the other.

6. In general, would you expect wash in winter from bare fields to be greater in northern or southern United States? Why?

7. Would it be desirable, from the standpoint of agriculture, entirely to prevent, if possible, soil erosion? Reasons?

8. Tile underdraining is in many cases effective in checking soil erosion. Why?

9. Plowing under straw, leaves, etc., was formerly a common practice. What value, if any, would this have?

10. In some of the mountainous areas of Italy, Austria, and other countries, forests are maintained in strips at right angles to the slope of the surface, while the land between is tilled. Why is this advantageous?

11. Explain in detail why plowing up and down a hill-side is unwise.

12. Other things being equal, would you expect crops to suffer more from protracted droughts on sandy or clayey soils? Why?

13. In parts of China it is customary to plant alternate rows of leguminous plants (like peas and beans) and grains. How does this benefit the soil?

14. Steel freight cars rapidly are replacing wooden ones, and re-enforced concrete (i.e. cement strengthened by steel) is being used for many new bridges in place of steel. Are these changes desirable from the standpoint of the conservation of natural resources? Reasons?

15. Why are gold and silver, the "precious metals," much less essential to man than coal and iron?

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CHAPTER XIV

CHANGES OF THE EARTH'S SURFACE DUE TO INTERNAL FORCES

Slow Crustal Movements

The crust of the earth seems to be firm and stable, except for occasional earthquakes and landslides, but it is in reality subject to very slow movements which, in the course of ages, produce great results. Such movements affect everything, from continents and ocean basins to minute particles of rock. Many of them result in warping the land and sea-bottom. Evidences of warping are so widespread that probably more of the earth's surface has been sinking or rising in recent geological times than has been standing still. Movements of land are seen most readily along coasts, because lands along the coast are compared easily with the level surface of the sea.

Movement of coastal lands. (1) Old buildings and docks, near sea-level when built, are found submerged in some places and well above the sea in others. Clearly, this means a recent change, at these places, in the relations of land and sea. (2) Beds of sediment containing sea-shells, deposited beneath the sea in recent times, are found now above the water in north Greenland, on the Pacific coast of the United States, in the West Indies, on the west coast of South America, and in other places. On the slopes of Mount St. Elias, Alaska, modern sea-shells have been found attached to the rocks just as they once grew, but several thousand feet above sea-level. (3) Conversely, there are drowned forests along some coasts. Thus north of Liverpool, England, when the tide is out, numerous stumps may be seen standing on the beach (Fig. 157). Since trees of the kind represented by these stumps do not grow in salt-water, we conclude that the land where they grew has sunk below the level of high water. On the coasts of New Jersey and North Carolina, too, there are stumps having similar histories, several feet below sea-level. Many other facts prove that the

land and sea change their relations to each other, and that most coast-lines have been affected by such changes in recent times.

The emergence of land may be due to (1) its rise, or (2) the sinking of the sea-level. Similarly, the submergence of land may be due to (1) its sinking, or (2) the rise of the sea. It is not possible to say, in all cases, whether it is the land or the sea-level which has changed; but it is certain that the sea-level rises and falls from time to time, and that the land also moves.

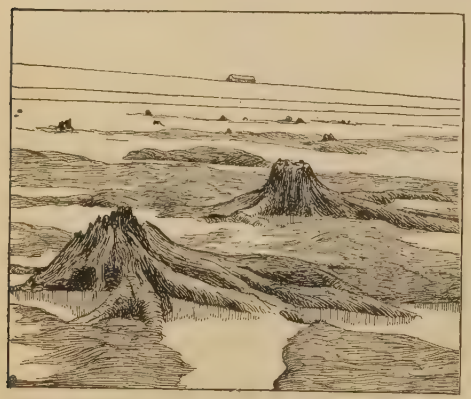

Fig. 157. Stumps laid bare on the beach at low tide; Leasowe, Cheshire, England. (From photograph by Ward.)

Causes of changes in sea-level. There are several things which may make the sea-level rise or fall. (1) The sinking of a portion of the ocean bed would lower the sea surface, while the elevation of a part of the sea floor would have an opposite effect. (2) Sediment washed from the land into the sea builds up the ocean floor, and so raises the surface of the sea. (3) Lavas poured out from volcanoes beneath the sea, and the deposits of corals and shell-bearing sea life, make the sea-level rise. (4) An increase or decrease in the total amount of land-water or ice would lower or raise the surface of the ocean. Since the oceans are all connected with one another, each of the above changes would affect the sea surface everywhere, and by the same amount. Other factors which will not be discussed here also affect the surface of the sea, and some of them make it higher in certain places than in others.

Changes of level in the interiors of continents. Changes of level are perhaps as common in the interiors of continents as along coasts, but they are not detected so easily, since there is no level surface like the sea with which to make comparisons. There are raised beaches about many lakes, as about the Great Lakes and Great Salt Lake (Fig. 158); but raised beaches about a lake may result from the lowering of the lake, either by the cutting down

of its outlet or by evaporation. They do not, therefore, prove a rise of the land. In many cases, however, the old shore-lines about lakes are not level, as they were when formed. Some parts of the old shore-line about former Lake Bonneville (the ancestor of Great Salt Lake) are 300 feet higher than other parts of the same line. An old shore-line about the east end of Lake Ontario is more than

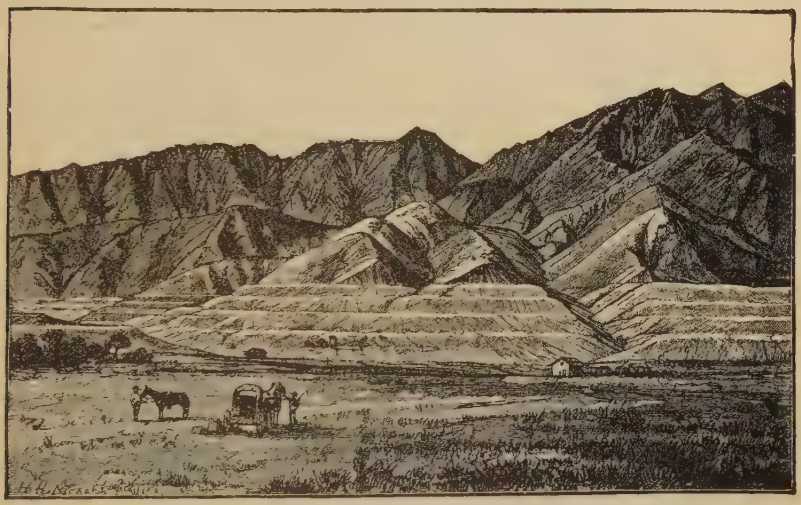

Fig. 158. Shore of former Lake Bonneville, Utah. (From photograph by U. S. Geol. Surv.)

400 feet above the lake, while the same shore-line passes beneath the water at the west end of the lake. Such warped shore-lines are found about many lakes, and show that the surface about the lake basins has suffered movement since the shore-lines were formed. Other phenomena, some of them discussed later, also show movement of large interior areas.

Ancient changes of level. Layers of rock, deposited long ago as sediment beneath the sea, are now found over great areas, far above sea-level. Most of the solid rock beneath the Mississippi Basin, for example, was laid down as sediment beneath the sea, as shown by the shells of the sea animals which it contains. In the Appalachian Mountains, rocks formed in the same way are found up to heights of several thousand feet; in the Rocky Mountains

up to 10,000 feet and more; in the Andes up to 16,000 feet; and in the Himalayas to still greater heights. It is certain, therefore, that changes of level have been great, and that vast areas have been affected. Great changes in the areas and in the relations of land and sea have occurred repeatedly in the distant past. Great and repeated incursions of the sea upon the continents, alternating with great extensions of the continents at the expense of the sea, have been among the most important events in the history of the earth, for they have shifted the sites of erosion and sedimentation, have modified climates, and have changed the distribution and conditions of plant and animal life. It is probable that in the course of the earth's history the lowering of the sea-level, because of the sinking of the ocean basins, has been greater than the rise of the sea-level, because of sedimentation from the land. This is perhaps the reason why wind, water, and ice have not been able to destroy the continents, as is their constant aim.

The past changes in the relations of oceans and continents perhaps have gone even further than indicated above. Geology gives us reason for thinking (1) that Europe has been connected with North America, by way of Iceland and Greenland; (2) that North America has been connected with Asia, by way of Alaska; (3) that the Mediterranean Sea once connected freely with the Indian Ocean to the southeast; (4) that a northerly arm of this extended sea, covering eastern Europe and western Asia, completely separated these continents; (5) that Great Britain was once a part of the continent of Europe; and even (6) that South America once was connected with other southern continents, perhaps by way of Antarctica.

Future changes of level. Changes of level between land and sea are likely to continue indefinitely, for the processes which cause them will occur in the future, so far as can be seen now, just as they have for ages past.

Earthquakes

Frequency and importance. Tremblings or quakings of the earth's surface occur frequently in many countries. Most of them are not felt, and are detected only by means of a delicate instrument (the *seismograph*) made to record them. For many years an average of several earth tremors a day have been recorded in Japan, and it has been said that some part of the earth's surface

probably is shaking all the time. The changes made in the surface of the land by earthquakes are slight, and they are important chiefly because a few strong earthquakes have occasioned great loss of life and property.

Fig. 159. Map showing in black the principal earthquake regions of the Old World. (Montessus de Ballore.)

Distribution. Figs. 159 and 160 show the principal earthquake regions of the world. Most of them lie near the edges of the continental platforms, though some (in Asia) are far inland. Most of them are mountainous areas, though some are lowlands. Earthquakes are perhaps most common in volcanic regions, though not confined to them. Not all the earthquakes of such regions have

been caused by volcanoes, for many of them have not occurred at times of volcanic activity. Except along the west coast of South America, the southern continents appear to be relatively free from earthquakes. This may be because earthquakes in most parts of

Fig. 160. Map showing in black the principal earthquake regions of the New World. (Montessus de Ballore.)

these continents would be less likely to be recorded than elsewhere. Some of the areas most affected by earthquakes are settled densely.

Causes of earthquakes. Earthquakes are caused in various ways. During movements of the earth's crust, great cracks or *fissures* sometimes are formed in the surface of the land (Fig. 161). The walls of fissures may be displaced, or *faulted*. Faulting has

caused many great earthquakes, the slipping of one great body of rock past another producing vibrations, which in some cases have spread far from the center of disturbance. An Alaskan earthquake in 1899 was caused by a sudden displacement of more than 40 feet, and the San Francisco disaster in 1906 resulted from a horizontal movement of 5 to 20 or more feet, along a line many miles in length. Earthquakes accompany violent volcanic eruptions, and in these cases the explosions which cause the eruptions are doubtless the cause of the quaking. Great landslides and avalanches may cause slight earthquakes, and it is probable that slumping on the slopes of deltas and on the outer faces of the continental shelves produces similar results. Very slight shocks are perhaps caused in still other ways.

Fig. 161. Fissure in floor of Kilauea, Hawaii.

It is probable that most earthquakes are incidents of the widespread movements to which the crust of the earth is subject, movements which are due primarily to the continued adjustment of the outside of the earth to a shrinking interior. In general, these movements are too slow to produce vibrations which we can feel; but they are sufficient, in rare cases, to produce great earthquakes.

Destruction of life and property. Except along the plane of slipping, the actual movement of the land surface during an earthquake is very slight; in most cases, but a small fraction of an inch. It is the suddenness of the shock which overthrows and destroys buildings and other objects on the surface. That a sudden but very slight movement of the ground may do this will be apparent when it is remembered that a quick, sharp tap on the side of a table may overthrow all loose objects upon it, even though the movement of the table itself is very slight.

Earthquakes in thickly settled regions have in some cases caused an appalling loss of life and property. The most disastrous earth-

quake in North America occurred in and about San Francisco in April, 1906. A large part of the city was burned by the fire which followed the shock. More than 700 lives were lost, and between 100,000 and 200,000 people were made homeless. Some 25,000 buildings (Fig. 162) were destroyed in the earthquake and fire, having an estimated value of more than $100,000,000. The preceding year (1905) a great earthquake in India (Kangra) destroyed nearly

Fig. 162. The new library building at Stanford University, after the earthquake of April, 1906. (Moran.)

19,000 lives and more than 112,000 buildings. About 100,000 people were killed in the earthquakes in southern Italy in 1908. In the case of such earthquakes, the shattered nerves and reduced efficiency of thousands of people, not otherwise injured, represent an enormous additional loss. In some countries where earthquakes are frequent, like Japan, much attention has been given to constructing buildings in such a way as to withstand the shocks.

When an earthquake disturbs the sea-bottom, a series of waves is set in motion. These waves rush upon neighboring coasts, and in some cases (e. g., in Sicily in 1908) they have done great damage. Millions of marine animals and plants were killed in Yakutat Bay during the Alaskan earthquake of 1899. The greater frequency of earthquakes in Nicaragua was one factor in favor of selecting the Panama route for the Isthmian Canal.

Vulcanism

Volcanoes

A volcano is a vent in the earth's crust out of which hot rock comes (Fig. 163). The hot rock may flow out in liquid form (called *lava*), or it may be thrown out violently in solid pieces. It is generally built up into a cone (Fig. 164), which may become a mound, a high hill, or even a high mountain. Quantities of gases and vapors are discharged along with the hot rock.

There is a hollow, called the *crater*, in the top of most volcanic cones. Craters vary greatly in size, some of the larger ones being two or three miles across. While the volcano is active, an opening leads down from the crater to the source of the lava, at an unknown depth.

Common phenomena of an eruption. In the *explosive type* of eruption, rumblings and earthquake shocks, due to explosions within the throat of the volcano, may occur for weeks or months previous to a violent outbreak. As the explosions become violent, dust, cinders, and solid pieces are shot forth and fall upon the sides of the cone, while the summit of the mountain is shaken. The clouds of condensed steam and dust rising from the crater darken the sky, and torrents of rain, falling on the fine dust, may form rivers of hot mud. Liquid lava may or may not accompany the discharge of solid material. In the *quiet type* of eruption, the lava rises in the crater and occasionally overflows its rim; but more commonly it breaks out through cracks in the side of the cone.

There is little or no burning in a volcano, for there is little or nothing to burn. There is, therefore, no smoke. What appears as smoke is mostly cloud, blackened by volcanic dust.

The products of volcanoes. *Lava* is a term applied both to the liquid rock which issues from a volcano, and to the solid rock which results from its cooling (Fig. 165). It takes on various forms as it becomes solid. If it hardens under little pressure, as at the surface, the gases and vapors which it contains may expand, and it may be converted into a sort of rock froth. Under other conditions it may form compact rock.

Most of the solid materials blown out of a volcano are pieces of lava which solidified before they were shot out, or during their flight in the air. They include masses of rock tons in weight, and smaller pieces of all sizes down to minute particles of dust (commonly

called *volcanic ash*). The dust in many cases is shot high into the air, and, being light, is scattered broadcast by the winds, some

Fig. 161. Taal Volcano, Philippine Islands, in eruption. (Gilchrist.)

of it coming to rest thousands of miles from its source. The liquid lava and the larger fragmental materials, on the other hand, stay

near the vent. As already indicated (p. 259), all rocks formed by the consolidation of lavas are igneous rocks.

The gases and vapors which issue from volcanoes are of many kinds. Some are poisonous, and some have temperatures so high as to be destructive to life, as in the case of Mont Pelée, in 1902.

Most soils produced by the decay of volcanic materials are rich in the mineral elements of plant food, and are highly productive when well watered. The volcanic soils of the Spice Islands (Moluccas), Java, and other islands of the East Indies, support a luxuriant vegetation. On the other hand, volcanic deposits weather slowly in a dry climate like that of Arizona, and support a scanty vegetation. The San Francisco Mountains, volcanic mountains near Flagstaff, Arizona, are high enough to compel an increase of rainfall from the passing winds, and their slopes therefore support a splendid forest in the midst of the surrounding desert. These contrasts emphasize the fact that climate may be the controlling factor in the productivity of the soil.

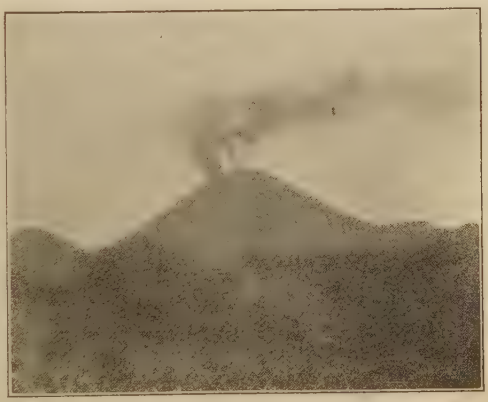

Fig. 164. Cone of Ngauruhoe, New Zealand. (Marshall.)

Number. The number of active volcanoes is not known definitely, but is estimated at 300 to 400. Something like two-thirds of them are on islands, and the remainder on the continents.

Distribution. The general distribution of active volcanoes is shown in Fig. 166. Many are arranged in belts, within which some are in lines. The most marked belt nearly encircles the Pacific Ocean. The volcanoes of the West Indies and of Java and Sumatra sometimes are considered as forming branches of the main belt. Outside this belt, volcanoes are numerous in and about the Mediterranean Sea, and there are many others which cannot be connected with any well-marked system.

Most volcanoes are in the sea or near it. Many are in moun-

tain regions, though they do not occur in all mountains. Many of the active volcanoes lie near the line where the continental plateaus descend to the ocean basins. This is perhaps the most significant feature of their distribution. Many volcanoes are associated with lands which have been raised or lowered recently.

Topographic effects of volcanoes. By making cones, volcanoes become in certain places important factors in shaping the

Fig. 165. Recent flow of lava from crater of Kilauea, Hawaii. (U. S. Forest Service.)

surface of the lithosphere. Some volcanic cones make mountains of great size, like Mt. Rainier (Tacoma) in Washington, Mt. Hood in Oregon (Fig. 167), Mt. Shasta in California, Orizaba in Mexico, and others. All those named are so high that snow-fields and glaciers are found on their slopes. Volcanic cones are far more numerous than active volcanoes, for the cones of many extinct volcanoes still remain.

Many small islands and some large ones are due chiefly or wholly to the building of volcanic cones on the ocean-bottom. The Aleutian Islands, the Hawaiian Islands, and many islands of Australasia were formed in this way. Iceland, too, is largely volcanic. Many volcanic islands are bordered by sea cliffs, and are therefore nearly inaccessible. The craters of a few nearly submerged volcanic

cones form excellent harbors. Breaches in the crater walls have admitted the sea, and serve as gateways for ships. Lyttelton, an important port of New Zealand, has a harbor of this kind.

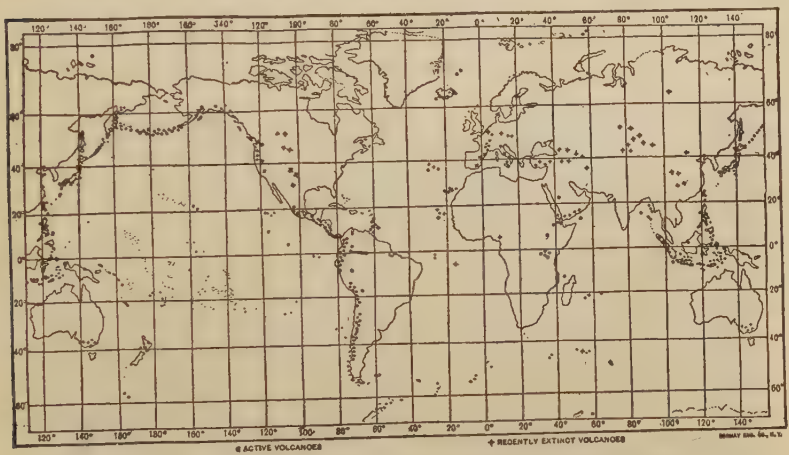

Fig. 166. Map showing the distribution of volcanoes. (Russell.)

Destruction of volcanic cones. Volcanic mountains, like all other elevations on the land, are subject to change and destruction. They may be destroyed partially *by violent explosions*. Again, the entire summit of a volcanic mountain may sink, leaving a great depression, or *caldera*. Crater Lake, Oregon (Fig. 168), the deepest lake in North America, occupies a caldera five or six miles in diameter, and 4,000 feet deep. The lake is surrounded by nearly vertical walls 900 to 2,200 feet high. Since the sinking of the top, a small cone, now an island in the lake, has been built.

Fig. 167. Mt. Hood, a snow-capped mountain.

Volcanic cones are destroyed also *by the slow processes of weathering and erosion* (p. 467). Wind and rain attack them as soon as they are formed, but the results are not conspicuous until the volcano is extinct and the cone stops growing. The many cones of extinct volcanoes in western United States are in various stages of destruction. Some in Arizona, California (Fig. 169), Idaho, and Oregon

Fig. 168. Portion of Crater Lake, Oregon. (Copyright by Kiser Photo Co.)

were formed so recently that they have suffered but little erosion. Fig. 170 shows a high mountain built by a former volcano. It still retains its conical form, but its steep upper slopes are furrowed by ravines and valleys, several of which contain glaciers. Fig. 171 shows an old volcanic mountain which probably once rivaled Vesuvius, now worn into irregular hills.

When a volcano ceases to be active, the passage from the interior may be filled with hardened lava. This may be much more resistant than the rest of the cone, and after the latter is worn away, the *plug*, which becomes a hill as its surroundings are removed, may still mark the site of the former volcano. Some of these volcanic *necks*, or *plugs*, are conspicuous. In central New Mexico a

number of them rise by precipitous slopes 800 to 1,500 feet above their surroundings.

Destructiveness. Like earthquakes, some volcanoes have destroyed great numbers of lives and much property. During an eruption of Vesuvius in 79 A. D., Pompeii, a city of about 20,000 inhabitants, was buried by cinders and ashes (Fig. 172), and Herculaneum was overwhelmed by streams of hot mud. Some of the later eruptions of this volcano also have been very destructive. That of 1631 was especially violent, destroying some 18,000 lives. One of the most violent and destructive volcanic eruptions of which there is record was that of 1883 in Krakatoa, an island in the Strait of Sunda, between Sumatra and Java. During a series of terrible

Fig. 169. Typical cinder cone, Clayton Valley, California.

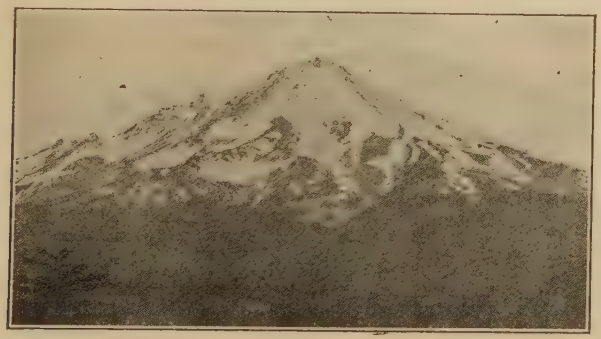

Fig. 170. Mt. Shasta, a typical volcanic cone furrowed by erosion, but retaining its general form. (U. S. Geol. Surv.)

explosions, about two-thirds of the island was blown away, and the sea is now nearly 1,000 feet deep where the center of the mountain formerly was (Figs. 173 and 174). Sea waves spread to Cape Horn, and possibly to the English Channel. On the shores of neighbor-

ing islands the water rose 50 feet. More than 36,000 persons perished, mostly by drowning, and 295 villages were destroyed, wholly or partially.

The volcano of Mont Pelée is on the island of Martinique, one of the Lesser Antilles, at the eastern border of the Caribbean Sea.

Fig. 171. Marysville Buttes in contour. North-central California. (U. S. Geol. Surv.)

Its cone descends by steep slopes to the sea on all sides but the south, where it is bordered by a plain on which the city of St. Pierre formerly stood. After slumbering for more than fifty years, the volcano became active in the spring of 1902. On May 8th a heavy black cloud, probably composed of steam, sulphurous vapors, and dust, and having an estimated temperature of 1,400° to 1,500° F.,

swept down through a gash in the crater's rim, and out over the plain to the southwest. In two minutes it struck the city of St. Pierre, five miles distant, which was demolished at once (Fig. 175).

Fig. 172. The ruins of Pompeii. (Doseff.)

Buildings were thrown down, statues hurled from their pedestals, and trees torn up. Explosions were heard in the city as the cloud reached it, and flames burst out, started either by the heat of the

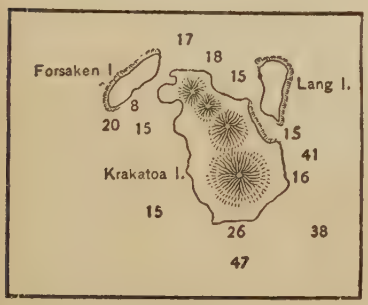

Fig. 173.

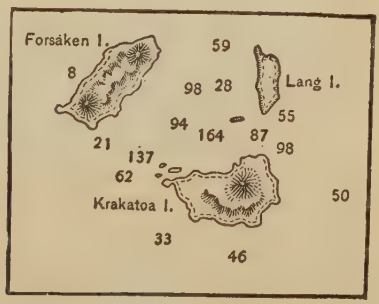

Fig. 174.

Fig. 173. Krakatoa Island and surroundings before the eruption of 1883.

Fig. 174. Krakatoa Island and surroundings after the eruption of 1883. The numbers indicate the depth of the water in fathoms (a fathom = 6 feet) in both figures.

gases, or the red-hot particles of rock which the gases carried. A few minutes later a deluge of rain, mud, and stones fell, continuing the destruction. With but two exceptions, the entire population,

increased to some 30,000 by refugees from the surrounding country, was wiped out of existence. The chief causes of death seem to have been (1) suffocation by the noxious vapors and gases, and (2) the great heat. Other causes of death were blows from stones thrown from the volcano, burns from hot rock, dust, and steam, and cremation in burning buildings.

Fig. 175. The ruins of St. Pierre, Martinique. (Hovey.)

Volcanic eruptions in Iceland in 1873 caused a considerable emigration from the island.

Igneous Phenomena Not Strictly Volcanic

Fissure eruptions. Lava sometimes rises to the surface through great fissures instead of through the relatively small vents of volcanoes. From such fissures floods of lava may spread over the surrounding country for hundreds of miles. (What determines the distance to which the lava flows?) Such lava floods once occurred in Oregon, Washington, and Idaho, where by successive flows the former hills and valleys were buried, and a vast plateau 200,000 square miles or more in extent was built up (Fig. 176). In some places, the nearly level surface of the plateau meets the mountains along its border somewhat as the sea meets the land, while islands of older rock rise above it.

In this lava plateau, the Snake River has excavated a great canyon 4,000 feet deep in some places, and 15 miles wide. The walls of the canyon show that in some cases successive beds of lava are separated by layers of soil in which the roots and trunks of trees are preserved.

An older lava plateau of greater size, and more dissected by erosion, occurs in central and southern India. Still others, now made rough by erosion, are found on the north coast of Ireland and the west coast of Scotland, and some of the islands off Scotland are remnants of an old lava plateau.

While fissure eruptions of lava sometimes build up plateaus or raise the level of the plains on which they spread, they do not commonly give rise to mountains; but mountains may be developed from them, as they are dissected by stream erosion.

Fig. 176. Lava flows of the Northwest.

Intrusions of lava. Most of the lava forced upward from great depths probably fails to reach the surface, and solidifies underground. Such rocks may be exposed at the surface through the wearing away of the rocks which overlay them. Indeed, much of the igneous rock at the surface is *intrusive rock*. Great masses of intruded lava may bulge up the overlying strata, making domes, some of which reach the size of mountains (Fig. 177). The Henry Mountains of Utah are examples. There are also deep-seated intrusions of still greater size and in many cases of irregular form (called *batholiths*). As exposed by the removal of the rocks which once covered them, some batholiths occupy thousands of square miles. In places, lava has been forced in between beds of rock in sheets (forming *sills*), and into cracks (forming *dikes*; Fig. 178).

Fig. 177. Diagram of a *laccolith*.

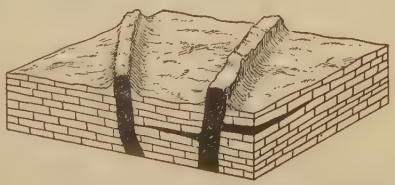

Fig. 178. Diagram of dikes and sills. What changes have occurred since the dike-rock was intruded?

Intrusions of lava may give rise to topographic features of importance after erosion has affected the regions where they occur, for the hardened lava (igneous rock) is in many cases harder than its surroundings. Many dikes form ridges. Intruded sheets of lava, if they have been tilted from a horizontal position,

may also form ridges, and these ridges may be so high as to be called mountains. The Palisade Ridge of the Hudson (Fig. 179), and most of the mountains of the Connecticut Valley, are examples. The steep ridges so important in the battle of Gettysburg are smaller examples of the same sort. Granite batholiths form the cores of many of the great mountain ranges.

Causes of Vulcanism

The causes of vulcanism lie outside the field of geography, and they are not well known. How the liquid rock is formed, the depth of its source, and how it makes its way toward the surface,

Fig. 179. The face of the Palisade Ridge, west of the lower Hudson River.

are unsolved questions. The old notion that volcanic vents are connected with a liquid interior has been abandoned.

It seems probable (1) that lava is being formed all the time, in spots, in the deep interior, and (2) that it is all the time finding its way toward the surface, but faster and in greater quantities at some times than at others. The regions where the crust is least stable, that is, where there is movement, are the regions most likely to afford the lava a place of escape.

Questions

1. At the west end of the island of Crete, in the Mediterranean Sea, old docks, near sea-level when built, are found many feet above the water on dry land. At the east end of the island, ancient buildings are under water. Was the change in the relation of land and sea thus recorded due to movement of the sea surface, or of the land? Why could it not have been due to the other?

2. How would the coast-line of North America be changed if the bottom of the Indian Ocean were to sink enough to lower the surface of that sea 200 feet?

3. Other things being equal, are buildings situated on solid rock or on loose sediments more likely to be destroyed in the event of an earthquake? Why?

4. Other things being equal, which are more enduring, volcanic cones built of lava or of cinders? Why?

5. Will soil form quickly or slowly on the recent (1902) volcanic deposits of Martinique and St. Vincent? Why?

6. To what extent may earthquakes and volcanic eruptions be predicted?

7. (1) What was the origin of the mountain in the right hand foreground of Fig. 180? The evidence? (2) Has much or little time elapsed since its formation? How told? (3) What is the probable history of the curving ridge at the left?

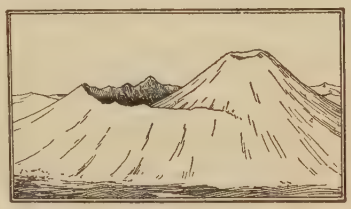

Fig. 180.

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The topics of this chapter are discussed at greater length in the larger text-books of Geology and Physiography, under *Changes of Level, Secular Changes of Level, Crustal Movements, Earthquakes, Volcanoes, etc.* Among the better books for use in connection with these and kindred topics are:

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CHAPTER XV

MODIFICATION OF LAND SURFACES BY EXTERNAL AGENTS

The surface of the land is being changed all the time by various agents, especially by wind, by water in the ground, by running water, by ice, and in minor ways by diverse forms of life.

The Work of the Wind

Winds modify land surfaces by removing dust and sand from certain places, and depositing them in others. Wind-driven dust and sand may wear exposed surfaces of rock.

Transportation. Transportation of fine materials by the wind is important where dust or dry sand is exposed to strong winds, as in semi-arid regions, and in deserts, which comprise about one-fifth of the land (11,500,000 square miles). Desert winds often sweep up "clouds" of dust which may be seen for miles, and a single storm may move millions of tons of dust and sand. The dreaded *simoon* of the Sahara has been known to destroy entire caravans, death resulting from suffocation in the dust-laden air. While transportation by the wind is most important in arid regions, it is by no means confined to them. Even in regions which are not arid, much of the dust in the air consists of fine particles of earthy matter blown up from streets, plowed fields, and surfaces not well covered with vegetation.

Particles of dust are much heavier than air, and gravity tends to bring them down. Yet they may remain in the air for a long time (1) because they are so small that they do not fall readily, and (2) because there are many upward currents in the air which carry the particles up in spite of gravity. As a matter of fact, the dust of the atmosphere always is settling, and the supply is being renewed constantly. Not only may dust remain in the air for a long time, but it may be carried great distances. A severe storm in March, 1901, carried dust northward from the Sahara, and

deposited it in diminishing amount over Europe as far as southern Denmark. In 1883, volcanic dust from Krakatoa (p. 306) was carried around the earth by the upper winds in about two weeks, its progress being indicated by the brilliant sunsets to which it gave rise.

Abrasion. Sand blown against a rock has the effect of a sand-blast, and wears the rock away. If some parts of the rock surface are harder than others, the less hard parts are worn more rapidly. Where abundant sand is driven by the wind, projecting rocks may be carved into fantastic forms (Fig. 181). Abrasion by wind-driven sand is of little consequence in a plain country where the climate is moist, and where the rock is covered with soil; but it is of much consequence in arid and semi-arid regions where the topography is rough, and where hills and points of bare rock are numerous (Fig. 182). In deserts and along sea coasts, telegraph poles have been cut off near the ground by wind-blown sand. In some such places, stones are piled about the bases of the poles, so that the stones, rather than the poles, get the sand blast (Fig. 183). The transparency of window glass has been destroyed in a few hours by wind-blown sand.

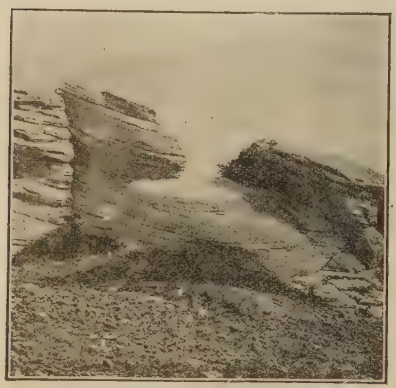

Fig. 181. Rocks carved by the wind. (Bastin.) What inferences may be made concerning the character of the rocks?

Wind deposits. Wind deposits of sand and loess (Fig. 184) have been described in connection with soils (p. 265). Sand usually is carried along within a few feet of the ground, and is therefore likely to lodge about any obstacle which blocks its way. Elevations of wind-deposited sand are *dunes*. They vary greatly in form, some being long, narrow ridges, and others irregular mounds, and they range in height from a few feet to more than 400 feet. Small dunes are much more common than large ones. Dunes are found mostly near the sources of abundant dry sand. They are common along much of the Atlantic coast of the United States, where sand is washed up on the beach by waves. After drying, it becomes the prey of the wind. Winds from the west blow this sand

into the sea; those from other directions, but especially from the east, drift it up on the land. Where westerly winds prevail, as

Fig. 182. Sandstone cliffs near Moab, Utah. (Cross, U. S. Geol. Surv.) What may be inferred concerning the climate of this region? The evidence?

in most of the United States, most of the dunes along valleys are on their east sides. Dunes abound over thousands of square miles in the semi-arid parts of the Great Plains, as in western Nebraska, western Kansas, and some parts of Wyoming. They reach their greatest development in still drier regions, such as the Sahara. In some places, dunes are the most conspicuous feature of the landscape.

Fig. 183. Telegraph pole in southern California; deeply cut by wind-driven sand. (Mendenhall, U. S. Geol. Surv.)

Sand is blown from the windward side of a dune and dropped on the leeward side, much of the time. This continued shifting of sand to the leeward side results in a slow migration of the dune. Farm lands, especially near sea coasts, have been covered in this way, and forests have been buried (Fig. 185). Sometimes sand buries buildings (Fig. 186), and in some places it causes much

trouble along railways (Fig. 187). So disastrous is the migration of dunes along some coasts that measures are taken to prevent it. If a dune is covered with vegetation, its position is not likely to change so long as the plants remain, for they hold down the sand. Trees, shrubs, and grasses which will grow in sand sometimes are planted on dunes as soon as the latter are formed, to prevent further drifting

Fig. 184. Deposit of loess near Vicksburg, Mississippi. The cut followed by the road has been developed by the wear of traffic and wind. (McGee, U. S. Bureau of Soils.)

(Fig. 188). This has been done at various points on the western coast of Europe, where land is valuable, and to some extent in our own country, as at San Francisco, where the westerly winds drift sand in from the shore. Fig. 189 shows the effect of a clump of trees in holding sand. All the dune except the part held by the roots of the trees has been blown away.

The amount of wind-blown sand not heaped up in distinct elevations probably far exceeds that in dunes.

Summary. The more important phases of the work of the atmosphere may be summarized here. (1) Of most importance is its work as an agent of weathering (pp. 261–262). (a) Through its

Fig. 185. Dunes advancing on a forest. Little Point Sable, Michigan.

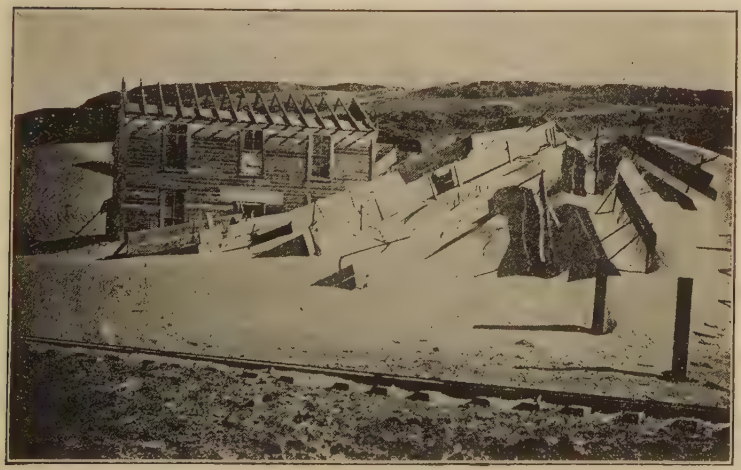

Fig. 186. The last house in Riggs, Oregon, a village overwhelmed by sand dunes. (Gilbert, U. S. Geol. Surv.)

effect on changes in temperature it influences the wedge work of ice, and the breaking of rocks by their expansion and contraction.

Fig. 187. Sand drifted over a railway, Rowena, Washington. One rail shows at the left-hand side. (U. S. Dept. of Agri.)

(b) The oxygen, carbon dioxide, and water vapor of the air unite chemically with various rock materials, and, by so doing, contrib-

Fig. 188. Sand dune reclamation, Manistee County, Michigan. (Sketch from photograph by Forest Service.)

ute to their decay. These processes prepare materials for removal by various transporting agencies. (2) The wind transports and

deposits large amounts of fine material. Although most extensive in arid regions, this work has affected all land surfaces. Since the wind deposits much dust and sand in the sea, the aggregate effect is to lower the lands and build up the ocean-bottoms. (3) Rocks are abraded by wind-driven sand. This is most important in deserts, where the atmosphere is, in many places, the chief agent of land reduction. (4) By controlling the conditions of evaporation and precipitation, the atmosphere makes possible the work of streams and of glaciers, and the existence of land life.

Fig. 189. The remnant of a dune held by roots. The surrounding sand not so held has been blown away. Head of Lake Michigan.

QUESTIONS

1. Why are there many large dunes on the eastern side of Lake Michigan, and only a few small ones on the western shore?

2. Describe the sequence of events recorded by Fig. 190.

Fig. 190. View on Little Point Sable, Michigan.

3. In many dune areas there are numerous depressions among the sand hills. In what ways may such depressions originate?

4. Why are dunes formed along some river valleys and not along others?

5. (1) What inferences may be made from Fig. 191 concerning (a) the character of the rocks, and (b) the climate? (2) What evidences of wind work are there in this picture?

Fig. 191. View in Red Mountain, Arizona. (Atwood.)

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See also general texts mentioned on p. 312.

Ground-Water

General considerations

The fate of rain-water. The average annual rainfall of the United States is about thirty inches. This means that a total of about 1,500 cubic miles of water (enough to cover New England to a depth of about 1,000 feet) fall as rain or snow in this country each year. It is estimated that about one-half of this water evaporates, that about one-third of it runs off over the surface, and that the remaining one-sixth is consumed by plants or sinks beneath the surface. The relative amounts disposed of in these different ways vary greatly from place to place, and from time to time. The proportion of the rainfall which sinks beneath the surface is determined chiefly by (1) the slope of the ground, (2) the porosity of the soil and bed rocks, (3) the nature of the rainfall (whether, for example, the water falls in a gentle drizzle or a driving downpour), (4) the character and amount of vegetation on the surface, and (5) the amount of water already in the ground. (What condition, under each of the above headings, would cause most water to sink under ground? Reasons.)

The ground-water surface. It is possible almost anywhere to dig wells deep enough so that they will have a constant supply of water. This means that the surrounding rocks are full of water below the level of the water in the wells. The surface below which the subsoil and rocks are full of water in any given region is the *water surface* or *water table* for that region. In swamps and marshes the water table is at or near the surface of the ground, while in arid regions it may be hundreds of feet below. In humid regions it is seldom more than 50 or 60 feet below the surface. The position of the water table also varies from time to time. It is higher after heavy rains, and lower during and after long droughts.

Amount of water underground. The pores and openings in the rocks below the water surface are full of water. Some porous rocks contain 30 per cent or more of their volume of water; very compact rocks may be able to hold only a fraction of 1 per cent. A porosity of 10 per cent means about 1 gallon of water per cubic foot. In general, rocks near the surface have more and larger pores and cracks than those at greater depths. Pores and cracks become very small at the depth of a few thousand feet, and probably none exist below a depth of five or six miles, because the rock pressure

is so great. If this is true, water does not descend to greater depths. There is water enough underground to form a layer at the surface having a depth variously estimated from 96 feet to more than 1,000 feet. It is probably not less than the mean of these two figures, and perhaps nearer the larger than the smaller. (What would need to be known in order to determine the amount accurately?)

Circulation of ground-water. Ground-water is moving constantly. This is shown, for example, by the constant flow of springs

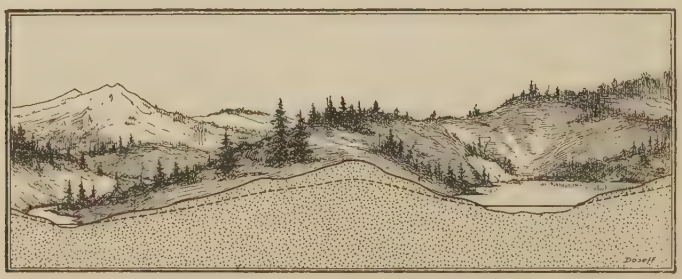

Fig. 192. Diagram showing the relation of the level of ground-water (the broken line) to the surface of the ground and to a lake and river.

and by the fact that after a well is pumped "dry," it soon fills again to the former level, because water seeps in from the surrounding rocks.

The reasons why ground-water moves may be understood readily. Rain does not fall equally everywhere. If there is a heavy shower in one part of a flat region where the ground-water surface is level, the soil and rock where the rain falls may become filled with water, and, as a result, the ground-water surface there is raised temporarily. Under these conditions, ground-water will flow from the place where the water surface is higher to places where it is lower. In the subsoil or bed rock, the water spreads more slowly than it would nearer the surface, because it does not move readily through the small pores and cracks.

The ground-water surface is not always level, even in a region where the rainfall is uniform. Other things being equal, it is higher beneath high land, and lower beneath low land (Fig. 192), and in this case, the water under the higher land moves out to lower lands. The tendency is for the water surface below the high land to sink until it is as low as that beneath the low land; but in moist climates

it rains so often that the water surface under the hills almost never sinks to the level of the water in the surrounding low lands, before it is raised again by rains.

Water which sinks to great depths commonly follows a devious course before again reaching the surface. At first its movement is chiefly downward, and is relatively rapid because of the many large

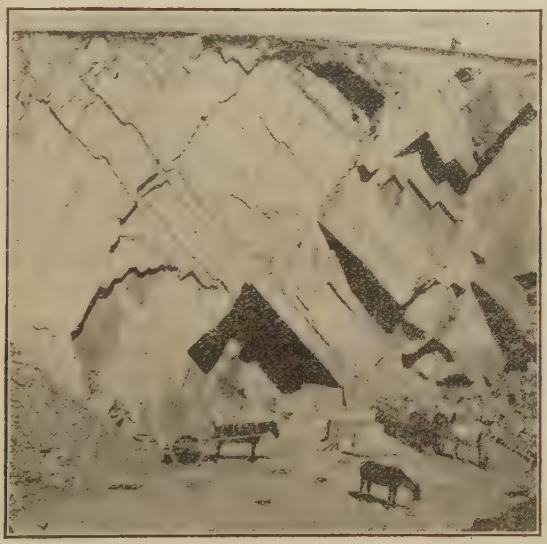

Fig. 193. View in quarry, Sturt Valley, South Australia, showing openings in the rocks. (Greenlees.)

cracks and pores in the rocks near the surface (Fig. 193). Farther down, its movement is largely sideways (Why?). In places it may be forced (by what?) toward the surface. It may flow slowly for many miles along a crooked course, through small openings, before it reaches a passageway leading to the surface. Through such an opening it may issue with great force as a spring or flowing well. Fig. 194 suggests the intricate circulation of the water which issues in a deep-seated spring. Some water flows underground to the sea or to lakes, and issues as springs beneath them. Much ground-water, too, seeps out in such small quantities that it does not appear to flow, and does not make a spring.

Ground-water moves in still other ways. Much of it is taken up by roots, passes up through the plants, and comes out through their leaves (is *transpired*) into the air. The amount of ground-water returned to the air through plants depends largely on (1) the density and character of the vegetation, (2) the temperature, (3) the relative humidity, (4) the velocity of the wind, and (5) the length of the growing season. (Compare the amount disposed of in this way in western Washington and Arizona; western Kansas and southern Florida.) It has been estimated that the amount of water returned to the air daily by forests through their foliage varies under different conditions from 1,000 to 20,000 or more pounds per acre, during the growing season. About 5,000 pounds of water are transpired by the foliage of corn-plants in the production of a bushel of corn. Again, water is evaporating from the ground most of the time, even in regions where the soil appears to be very dry. It is probable that nearly all the water which sinks beneath the surface comes up again sooner or later, in some of these ways; but a little unites with solid mineral matter, as in iron rust (p. 261).

Fig. 194. Diagram showing the intricate underground drainage which issues in a deep-seated spring. (Geikie.)

The rate at which ground-water moves depends chiefly on (1) the porosity of the rock or soil, and (2) the pressure of the water. The rate at which water seeps through soils from irrigating ditches in the West is in most cases from one to eight feet per day; but in very porous soils it is sometimes as much as 50 feet per day. In a widespread formation of sandstone which underlies southern Wisconsin and northern Illinois, the rate of movement of ground-water has been estimated at half a mile a year. At this rate, rain-water which enters this formation 100 miles from Chicago would reach that city in about 200 years.

Knowledge of the circulation of the upper part of the ground-water is important to every family using well-water for domestic purposes. Polluted well-water is very common on farms which might have pure and wholesome water. Great numbers of wells

are so situated that ground-water moves toward them from cesspools and stables. Largely as a result of this, typhoid fever is more common in many farming regions than in most cities.

Uses and functions of ground-water. Ground-water is of vital importance in the economy of the earth and in human affairs. (1) It is important to plants. It dissolves the mineral elements of plant food and carries them to the roots. The amount of water available for plants is the most important factor conditioning their life in many regions. (2) Underground water supplies all springs and wells, the sources from which perhaps three-fourths of the people of the United States obtain their water for domestic use. (What are the other possible sources of supply?)

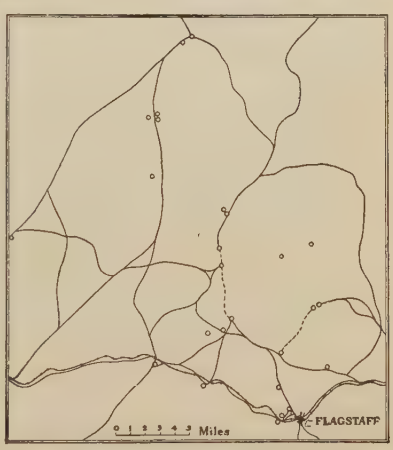

Fig. 195. Map showing springs (by circles) and roads in the region of Flagstaff, Arizona. (From San Francisco Mountain Sheet, U. S. Geol. Surv.)

The distribution of population in eastern United States was influenced greatly by running water and natural springs, until modern methods of well-digging were developed. Absence of springs, and dependence for two years upon the brackish water of the James River, were one cause of the high death-rate in the Jamestown colony. A supply of wholesome water helped to determine the location of the Pilgrim colony at Plymouth, and of the Puritan settlement at Boston. Many of the stockaded villages of the early western frontier were so located as to command a supply of water in the event of an Indian siege. The settlement of certain inter-stream areas in southern Wisconsin and in Illinois was delayed for years, partly because of the difficulty and expense of digging wells. In the arid West, springs and watering places determine the location of many villages and farms, and influence the course of trails and roads (Fig. 195). Their location is indicated on many maps for the benefit of travelers.

Because of the intimate relation of ground-water to plant, animal, and human life, it is highly important that the water table be kept near the surface of the ground. It is estimated that in eastern United States it has been lowered from 10 to 40 feet over large areas by cutting off forests and by careless methods of tillage

which have increased the proportion of the rain-water which runs off over the surface. Indeed, it is estimated that at least three-fourths of the shallow wells and springs have failed in this part of the country. (3) Ground-waters bring about important changes in the character of the rocks through which they pass. These changes take place slowly, but they are going on all the time.

The different kinds of springs and the work of ground-water may be discussed in greater detail.

OUTFLOWING WATERS

Hillside and fissure springs. Fig. 196 illustrates two kinds of springs. In the one, water descends through a more or less porous bed of rock, *c*, to a layer, *a*, which is compact. Much of the water flows along this layer until the latter comes to the surface (*out-*

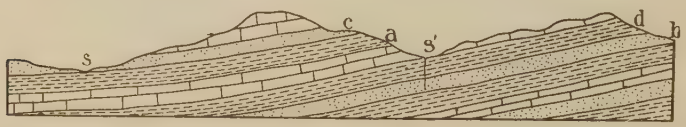

Fig. 196. Diagram to illustrate two types of springs, as explained in text.

crops), and there the water issues as a *hillside spring*, *s*. The great majority of springs are of this class, and most of them are small. In the other case (Fig. 196), the water moves through the porous layer, *b*, under pressure, until it reaches a crack which leads up to the surface. If the crack is open enough to afford a passageway, the water will follow it up to the surface, as at *s'*, forming a *fissure spring*. In such a situation there will be a spring only when the opening is lower than the water surface in the layer of rock which carries the water. This sort of spring is similar to a flowing well in principle, though in the latter case the opening is made by man.

Artesian wells. Formerly, artesian wells were regarded as the same as flowing wells. Now, the name "artesian" often is applied to deep, drilled wells, whether they flow or not. Fig. 197 illustrates the conditions necessary for flowing wells. They are: (1) A porous layer or bed of rock, *A*, underlying one which is not porous, and which prevents the water from escaping upward until it is penetrated by the well hole, *W*. The porous bed must come to the surface in a region which is somewhat higher than the site of the well; and (2) enough rainfall where the porous bed comes to the sur-

face to keep that bed well filled with water. Under these conditions, the water will gush up (Fig. 198), if a hole is made down to it.

Fig. 197. Diagram illustrating the conditions necessary for flowing wells.

Flowing wells may be but a few feet deep, or they may be thousands of feet deep. Thus there is one in St. Louis nearly 4,000 feet deep, and many in New Jersey less than 100 feet in depth. Many villages and small cities get their water from artesian wells; but great cities, such as New York and Chicago, could not get enough in this way. Brooklyn obtains a part of its supply in this way, its artesian wells having a capacity of about 22,000,000 gallons per day. In parts of the West, artesian waters are used extensively for irrigation, as well as for domestic and other purposes. The Black Hills of southwestern South Dakota receive much more rain than the surrounding plains (hence the dark forests which suggested their name). Porous sandstone beds coming to the surface about their flanks carry a part of this rain-water eastward for many miles beneath the plains. East of the upper Missouri River more than 1,000 artesian wells tap these sandstones,

Fig. 198. An artesian well at Lynch, Nebraska. Flows more than 3,000 gallons per minute. (Darton, U. S. Geol. Surv.)

and obtain large quantities of water. In the Dakotas and probably in other artesian areas more wells have been drilled than are needed, and when not in use (in many cases this is the greater part of the time) the water from the flowing wells has been allowed to run off freely. This has reduced so greatly the pressure and the amount of water available, that villages and cities, formerly abundantly supplied from artesian wells, have been compelled to seek other sources of supply. In some of the arid states where the water problem is critical, as in California, strict laws exist to prevent the waste of artesian and other underground waters (Fig. 199). The San Bernardino artesian basin of southern California covers less than 175 square miles, but is of great importance to the orange orchards. Here artesian and other waters are used with great skill. It is estimated, for example, that water in passing from the upper Santa Ana River (the chief stream of the district) to the sea is utilized for different purposes at least eight times.

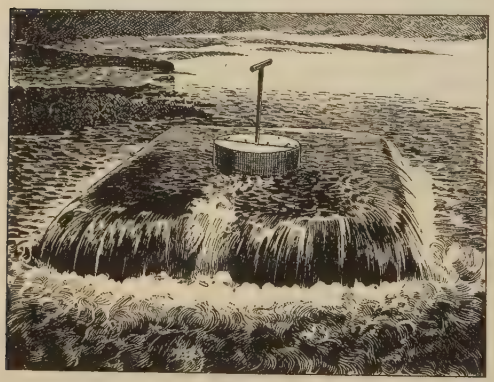

Fig. 199. An artesian well in southern California, showing method of shutting off the water when not in use.

Geysers. Geysers are hot springs which erupt from time to time (Figs. 200 and 201). So far as known, they occur only in a few regions of recent volcanic activity, Yellowstone National Park, New Zealand, and Iceland. From a few geysers water is ejected to a height of 200 feet or more, by steam produced at some point in the geyser tube below the top of the water. It is believed that hot volcanic rocks make the water boil, and the expansion of the steam formed causes the eruptions. (How will the cooling of the rocks affect the frequency of eruptions? What will be the ultimate fate of existing geysers?) Although interesting, geysers are of little importance.

Other hot springs. Some springs are warm, and a few are hot. Where spring-water is hot, it is in some cases because it has been

in contact with lava which came up from greater depths so recently that it has not yet become cold. In other cases the heat may be due to chemical changes taking place beneath the surface. There are more than 3,000 hot springs in the Yellowstone National Park, and many others in different parts of the country.

Mineral and medicinal springs. All spring-water has some mineral matter in solution; but a spring is not commonly

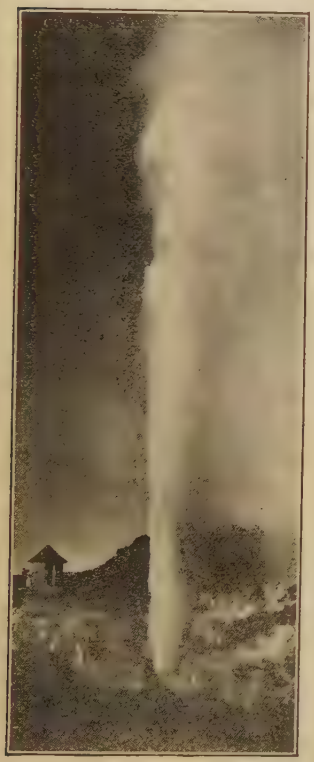

Fig. 200. Fig. 201.

Fig. 200. The Wairoa Geyser, New Zealand. Shoots 1,500 feet. (New Zealand Gov't Tourist Dept.)

Fig. 201. Waimangu Geyser, New Zealand. (Muir and Moodie.)

called a *mineral spring* unless it contains (1) much mineral matter. (2) mineral matter which is unusual in spring-water, or (3) mineral matter which is conspicuous either because of its color, odor, or taste. Many mineral springs are thought — and some rightly — to have healing properties, and so are known as *medicinal springs*. Many of the

famous watering-places and resorts for invalids are at hot mineral springs. The Hot Springs of Arkansas, Virginia, South Dakota, and Carlsbad (Bohemia) are examples. Many springs which are charged with gases are called mineral and medicinal, even though their waters are worthless for healing purposes. In 1910 mineral water was sold from about 700 springs in the United States. The amount of water sold was more than 62,000,000 gallons, valued at about $6,300,000.

WORK OF GROUND-WATER

Solution. All water which comes out of the ground has in solution some mineral matter dissolved from the rock through which the water has passed. Pure water does not dissolve mineral matter readily; but rain-water is not pure, for it dissolves gases from the air, and in sinking through the soil takes up the products of plant decay. With these impurities in solution, ground-water dissolves most sorts of mineral matter more readily than pure water would. The amount of mineral matter brought to the surface through springs is very great. Thus the springs of Leuk (Switzerland) have been estimated to bring to the surface more than 2,000 tons of gypsum in solution yearly. By removing their soluble constituents, ground-water helps to make rocks crumble, and so to form soils (p. 261).

Much of the ground-water finds its way to rivers after it seeps out. The larger part of the mineral matter in solution in rivers has come from ground-water which has flowed to them. All the rivers of the earth are estimated to carry nearly five billion tons of mineral matter to the sea in solution each year. The transfer of so much mineral matter in solution from land to sea, lowers the land.

Some of the mineral matter carried to the sea in this way remains in the sea-water. Thus, most of the salt which has been carried to the sea remains there, probably, to this day. On the other hand, much of the mineral matter taken to the sea is used by sea animals (and some plants) for making their shells, tests, and bones, and these are left on the sea-bottom when the organisms die.

Caverns and cavern life. By the dissolving work of ground-water, rock is made porous. Small pores and cavities are more numerous than large ones, but some of the openings produced in this way, such as Mammoth Cave in Kentucky, and Wyandotte Cave in southern Indiana, are very large. Such caves occur chiefly

in limestone, for this is the most soluble of the common rocks. An underground cave is not, as a rule, one great chamber, but is made up of many chambers connected by smaller passageways (Fig. 202).

Caverns do not furnish the conditions favorable for most sorts of life, for most plants and animals need light; yet there are several varieties of cavern animals, some living in the water and some in the damp air. These animals are so like those living above ground in the same region, that they are thought to be the descendants of animals which got into the caves from the surface.

Fig. 202. Vertical section of a cave in France. (After Robin.)

Cave animals show some peculiar features. They are colored less brightly than their relatives above ground. This is probably because of the absence of sunlight, which seems to have much to do with producing color in animals. Some cave animals have good eyes, some have imperfect eyes, and some have none. From these and other facts, we infer that the eyes of animals in dark caves tend to disappear. A third peculiar feature of cavern animals is the good development of their organs of touch. In the darkness the sense of touch is much more useful than sight.

In Europe, certain caverns were the homes of primitive man, as shown by the human bones and the tools of various sorts which are found in them. Here, too, are found the bones of large animals which were killed for food or fur, and taken to the caves. On some of the bones of such animals, and on pieces of slate or wood, there are drawings, some of which are of animals no longer living in the region where the caves are. From this we infer that the people who lived in the caves dwelt there a long time ago.

Deposition. After dissolving mineral matter, ground-water sometimes leaves a part of it in the pores and cracks of the rocks through which it flows. When cracks in the rocks are filled or partly filled by mineral matter deposited from solution, the fillings become *veins* (Fig. 203). Many ores of gold, silver, lead, zinc, copper, and other metals, occur in veins. Originally, most of the metals were scattered widely through the rocks, usually in the form of com-

pounds. They first were dissolved, and then deposited by ground-waters in the cracks and openings where they are now found. Thus the work of ground-water has made the great deposits of most ores, so important to mankind (pp. 284–287). Ground-waters also deposit mineral matter among particles of loose sediment, cementing them into firm rock.

Mineral matter brought to the surface by ground-water may be deposited there, as the result of various causes. (1) When water evaporates, the mineral matter dissolved in it is left behind. This is one reason why kettles in which water is boiled become coated with mineral matter. (2) Certain gases dissolved in water help it to dissolve mineral matter. If water contains much gas, which later escapes, as it is likely to when the water is heated or when it comes to the surface, some of the mineral matter in solution may be deposited. (3) Warm spring-water may give up what it holds in solution when it cools. (4) Microscopic plants grow in the waters which issue from some hot springs, as in Yellowstone Park, and by some process not well understood, extract mineral matter from the water, and cause it to be deposited.

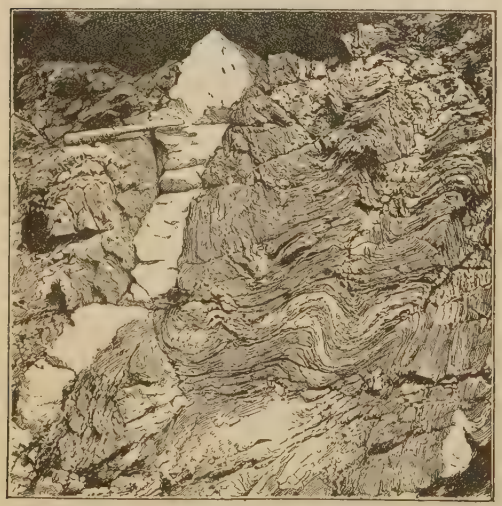

Fig. 203. A quartz vein (the white band) in metamorphic rock. Muchals Caves, Kincardineshire, Scotland.

Solution and deposition may be going on at the same time, and even in the same place. Thus the original material of a buried shell may be dissolved and carried away at the same time that other material is left in its place, preserving the form of the shell. In the same way, wood may be replaced by mineral matter, giving rise to *petrified wood*, or wood "turned to stone." Such changes prob-

ably take place slowly, the mineral matter which was in solution in the water replacing the woody matter as it decays.

Mechanical work. Abrasion by ground-water is slight, since ground-water rarely flows in strong streams. Indirectly, ground-water helps to bring about changes of another sort. When the soil on a steep slope becomes full of water, its weight is increased greatly, and the water in it makes it move more easily. Under these circumstances, it sometimes slides down. Such movements are known as *slumping* or *sliding*. If the slide is large, it usually is called a *landslide* (Fig. 204). Slumping is very common on the slopes of hills composed of clay or other loose matter. Many landslides have been very destructive. In 1903 there was a slide on Turtle Mountain, Province of Alberta, Canada. A huge mass of material nearly half a mile square, and probably 400 to 500 feet deep, suddenly slid down the steep face of the mountain, into the valley below. The length of the slide was about two and a half miles, and it is estimated that the time which it took was not more than 100 seconds. The heavy rainfall of the preceding year had filled the rock with water, and the earth tremors which occurred shortly before the slide are believed to have hastened the catastrophe. Extensive mine tunnels at the base of the mountain may have aided by making the understructure less stable. Many buildings were destroyed, and many lives lost.

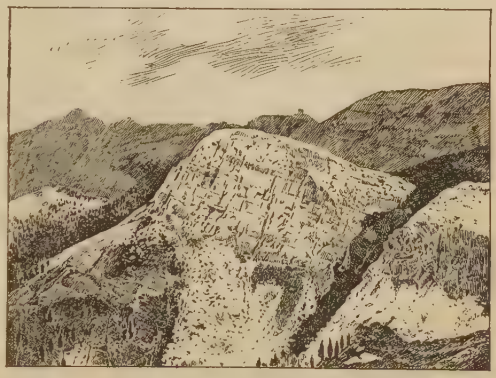

Fig. 204. A landslide. (Sketch from photograph by Hole.)

Water in the soil and upper rocks works with gravity in the extremely slow, down-slope movement of surface material. This sort of movement is *creep* (Fig. 205). It is usually too slow to be seen, but it results in the accumulation of mantle rock at the bases of slopes.

SUMMARY

From the preceding paragraphs it is apparent that the existence and work of ground-water are matters of great importance. (1) Without water in the soil most plants could not live, and the amount available largely controls both the density and the character of the vegetation. (2) Chiefly through its influence on plant life, ground-water helps to determine the distribution and occupations of people. (3) Ground-water is the source of all wells and springs. Ground-water, seeping out, maintains the flow of most streams. (4) Ground-water may modify the character of rocks in several ways: (a) by removing soluble constituents; (b) by depositing new material in rock cavities; (c) by replacing old material with new; and (d) by favoring new chemical combinations. These changes must have occurred on a vast scale, for ground-waters have been at work for untold millions of years. As a result, soils and useful ores have been accumulated, and igneous and sedimentary rocks have become

Fig. 205. A ravine near Crawfordsville, Indiana, showing trees leaning down-slope, in part because of creep. The surface material creeps faster than that below, tipping the trees toward the axis of the ravine.

Fig. 206. Diagram of wells on a hill-side. The line below the surface represents the water table.

metamorphic rocks. (5) The mechanical work of ground-water is relatively unimportant, but widespread. The creeping and slumping of surface material are in some cases due partly to ground-water.

QUESTIONS

1. Which of the wells shown in Fig. 206 would you classify as safe, and which as unsafe sources of water for domestic use? Why?

2. In order to contain water constantly, must wells extend farther below the surface of the ground on hill tops or in valley bottoms?

3. Make a diagram showing (1) the position of the water table during the wet and during the dry season, and (2) the cross-sections of wells which (a) never, (b) occasionally, and (c) frequently "go dry."

4. In order to increase the flow of water, dynamite is sometimes exploded in wells. Why does this in many cases produce the desired effect? Would it be more likely to succeed with wells penetrating hard, brittle rocks, or soft, tough rocks?

5. Why is it hard in some places to get a supply of water in a limestone country?

6. Make a diagram showing (1) the surface of the ground in a hilly region containing a lake, a swamp, and a river, and (2) the position of the water table beneath this surface (a) after continued rains, and (b) during a protracted drought.

7. What effect does the irrigation of arid lands by water led in ditches from streams have upon the position of the water table? How does this affect the question of the acreage which ultimately may be irrigated?

8. Why are the inscriptions on many old tombstones indistinct?

Fig. 207. The Minaret, Jenolan Caves, N. S. W., Australia. The deposits which extend downward from the roof of the cave, icicle fashion, are *stalactites;* those which are built upward from the floor are *stalagmites*.

9. Describe the characteristics of a climate which should (1) hinder, and (2) favor solution by ground-water.

10. What things may have caused the deposition, from solution, of the material of the stalactites and stalagmites shown in Fig. 207?

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See also general texts mentioned on p. 312.

THE WORK OF STREAMS

Running water is more effective than wind in changing the surface of the land over which it moves, largely because water is about 80 times heavier than air. Furthermore, much of the work of running water is concentrated in valleys. The work of running water is also much more important than that of ice, because water moves more readily and affects larger areas. It is true that glaciers have been much more extensive than now, at different times in the past, but this was the case, so far as known, only for comparatively short periods. On the other hand, streams are numerous in most lands, and have been for untold ages. Even in deserts few large areas are without valleys which contain at least temporary, wet-weather streams. All in all, running water is more important than all other agents in shaping the details of land surfaces.

Streams modify land surfaces (1) by moving loose material to lower levels, much of it to the sea, (2) by wearing their channels, and (3) by depositing their excess loads in various forms. These phases of river work, together with their topographic results and some of their human relations, are discussed below. The use of streams, as for commerce, manufacturing, and irrigation, is discussed in Chapter XVI.

TRANSPORTATION

Gathering sediment. As rain-water flows down the slopes on which it falls, it carries particles of earth to the streams below. A stream gets much sediment in this way, if the immediate run-off flows over bare, steep slopes of loose material, and little, if it flows

over slopes well covered with vegetation, such as grass land or forest. Water may flow down slope in a sheet, or it may be gathered into streamlets. It carries more sediment in the latter case, because such water flows faster. Besides the sediment brought to it by sheet-wash and temporary streamlets, a stream also gathers material from its bed and banks.

A stream is not a single, straightforward current. When water runs through an open ditch or gutter, some of it may be seen to move from sides to center, and some from center to sides, while eddies are common. These lesser currents in the main current are especially distinct where the water flows swiftly. Streams show the same features. These phenomena show that there are numerous subordinate currents in the main current of a river, and that they move in various directions. Many of them are caused by the unevenness of the bed of the stream (Figs. 208 and 209). The subordinate upward currents frequently carry sediment up from the bottom of the stream, bringing it into suspension.

Fig. 208. Diagram to illustrate the effect of irregularities, *a* and *b*, in a stream's bed, on the current striking them.

Ground-water dissolves rock slowly, and springs bring some of this dissolved matter to streams (p. 330). Most dissolved substances are invisible, and, unlike mud, remain in the water even after it has become quiet. The amount of matter carried to the sea in solution each year by all the rivers of the earth has been estimated to be about one-third as much as the sediment carried by them (p. 330).

Carrying sediment. Coarse materials, such as pebbles, in most cases are rolled along the bottom, while fine materials, such as mud and silt, are likely to be carried in suspension. The movement of the coarse materials rolled along the channel is understood easily, but the behavior of the fine sediment in suspension needs explanation.

Mud is composed chiefly of tiny particles of rock, nearly three times as heavy as water; hence they tend to sink all the time. But as gravity brings them down, many are caught by minor upward currents (Fig. 208), and carried up in spite of gravity. *It is largely by means of these minor upward currents in the main current, that sedi-*

ment is kept in suspension. Particles of sediment suspended in a stream are dropped and picked up again repeatedly, and the long journey of any particle is made up of many short ones.

Amount of load. The amount of sediment a stream carries depends on (1) its swiftness, (2) its volume, and (3) the amount and kind of sediment which it can get. Swift and large streams can carry a heavier load than slow and small ones. The effect of velocity on the carrying power of streams may be seen in most creeks and rivers which are wider in some places than in others. Where the channel is narrow, the current is swift, and here, in many cases, all fine material has been swept away, leaving only pebbles and larger stones in the channel. Where the channel is wider, and the current slower, the bottom of the same stream may be covered with sand or mud. By narrowing the channel of the Mississippi by making jetties near one of its mouths, in 1875, James B. Eads not only prevented further deposition of sediment there, but forced the river to clear out its own channel. This change permitted larger ocean vessels to reach New Orleans at all times.

The amount of material which certain streams carry to the sea has been estimated. For a given river, the estimate is made by calculating the average amount of water (in gallons or in cubic feet) discharged by it each year, and then determining the average amount of sediment in each gallon or each cubic foot. It was estimated long ago that the Mississippi River carries to the Gulf of Mexico more than 400 million tons of sediment each year, an average of more than a million tons a day. It would take nearly 900 daily trains of 50 cars, each car loaded with 25 tons, to carry an equal amount of sand and mud to the Gulf. This sediment represents a great loss to the country (p. 267), for most of it would make soil of great fertility, if it were on land. All the rivers of the earth are carrying perhaps 40 times as much as the Mississippi.

CORRASION

How streams wear rocks. As already stated (p. 336), streams wear (*corrade*) their channels. If the channel is muddy, the moving water picks up sediment; if sandy or gravelly, sediment is rolled along the bottom. Many streams flow on solid rocks, and they gather load even from them. Rock exposed to water, as in the bed of a stream, decays. As it decays, it crumbles, and the crumbled parts are swept away by a swift current. Again, the sand and

gravel rolled along by a stream wear its bed even if it is of hard rock. Subordinate currents sometimes drive the sediment in suspension against the bottom or sides of the channel with similar results. The bits of sediment which a stream carries therefore become tools (Fig. 209), with which even hard rock is worn away. Clear water, flowing over firm, hard rock, effects little mechanical wear. This

Fig. 209. The tools of a river. Stream-worn pebbles in the bed of the St. Joe River, Washington. (Tolman.)

is shown by the fact that in many cases even large rivers flowing from lakes have "mossy" channels. (Why do such rivers have few tools?)

Rate of erosion. The rate at which a stream wears down the surface over which it flows depends largely on (1) its *volume*, and this depends chiefly on the amount of precipitation, and on the size and configuration of the area draining to it; (2) its *velocity*, which is determined chiefly by its slope, or *gradient*, and its volume; (3) the *character of its bed*, especially the resistance of its materials; and (4) the *load* which the running water carries. To work most effectively, the water must have tools enough to enable it to cut rapidly, but not so many that the energy expended in moving them retards its flow seriously. Since the factors named above vary

greatly, the rate at which the land is being degraded is very unequal in different places. It was calculated recently that the average rate of reduction for the United States is about 1 inch in 760 years; but the rate varies from an average of 1 inch of reduction in about 440 years in the Colorado Basin, to 1 inch in about 3,900 years in the basin of the Red River of the North (Fig. 210).

FEATURES DEVELOPED BY STREAM EROSION

River Valleys

The depressions in which rivers flow are their *valleys*, and in the making of valleys streams have been the chief agents. Valleys are of much importance to mankind.

River valleys centers of human activity. Most of the great valley lowlands of middle latitudes are settled densely, because of their fertile soils, favorable topography, and facilities for communication. Probably more than one-fourth of the people of eastern United States live on alluvial lands.

The valleys of the United States have been sought out for settlement from the beginning of its history. New York history began at the mouth of the Hudson, Pennsylvania history in the valley of the Delaware, and that of Virginia on the banks of the James. Later, various valleys became highways of expansion toward the interior. The overflow from the settlements of the coastal lowlands of Massachusetts passed over the uplands of crystalline rock to the west, to the inviting bottom lands and terraces of the Connecticut Valley. As years passed, this great valley led settlers northward into western New Hampshire and Vermont. The latter was at first called "New Connecticut," because of the large number of settlers who had come from Connecticut. The Ohio Valley was one of the first sections of the interior to be settled, and for many years the Ohio River was a main highway of westward expansion. The upper Rio Grande Valley guided settlers northward from Mexico into the United States. The Platte Valley directed many fur traders and trappers across the Great Plains; it was followed by the Mormons on their way to Utah; along it ran the Oregon Trail and the first transcontinental railroad; and it was the greatest gateway into Nebraska when, in the fifties, the latter began to be settled. Many other examples of the rôle which valleys have played in expansion and settlement might be given.

The larger rivers of eastern United States were long the great highways of trade and travel. Much of the Interior depended almost exclusively on the Mississippi and its tributaries as outlets to market, before the building of railroads (p. 420). The latter, in many cases, followed the valleys to share in the trade already established, but in areas of rough topography, the railroads followed the rivers also because the valley bottoms afforded the easiest

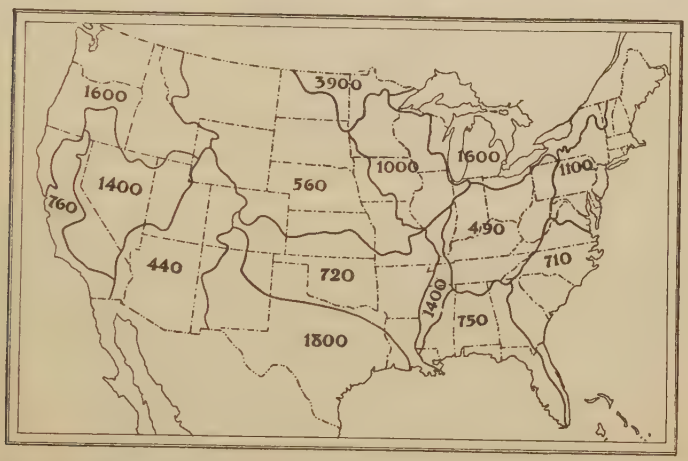


Fig. 210. Rates of land reduction by stream erosion in the United States. The figures are the approximate number of years required for one inch of reduction. (Dole and Stabler, U. S. Geol. Surv.)

grades. In the future, the larger rivers of the United States probably will be used more than now to supplement railroad transportation (p. 438).

Many valleys are grown-up gullies. Many valleys are enlarged gullies. A gully started during one shower (Fig. 211) is made deeper, wider, and longer by the next. As the result of repeated showers year after year and, in many places, repeated meltings of snows, the gully grows to be a ravine, and later a valley. Not all gullies, however, become valleys. Many gullies may start on a slope (Fig. 212), but as they grow, some are so widened as to take in others (Fig. 213), and the number is reduced. As gullies develop, the heads of some work back faster than others (Why?), with the result that many gullies are arrested early in their development,

as shown in Fig. 212. But a small proportion of all that start become ravines, fewer still become small valleys, and the number of valleys which attain great length is very small.

Fig. 211. A gully developed by a single shower.

Growth of gullies should be prevented. Much land in the United States has been ruined (Fig. 214) and much more injured, for agricultural purposes, by the formation of gullies. There are many examples of such land in the southern Appalachians, where, on unprotected surfaces, gullies form and grow rapidly because the slopes are steep, the rainfall heavy, and much of the surface material is eroded easily. Surfaces of this sort should, as a rule, be kept covered with trees, and given over to the growth of forests. But serious gullying is by no means confined to mountain areas (Fig. 215). Indeed, the problem of checking the growth of gullies is country-wide. They can be controlled best while still small. One way of doing this is by filling them with brush (Fig. 216). Fig. 217 shows one method of restraining the water of mountain torrents.

Fig. 212. Gullies on slope above a valley flat.

How valleys get streams. Water commonly flows in gullies only when it rains or when snow melts, and for a short time

afterward; their active growth is therefore intermittent. But many valleys made from gullies have permanent streams, so that their enlargement goes on all the time.

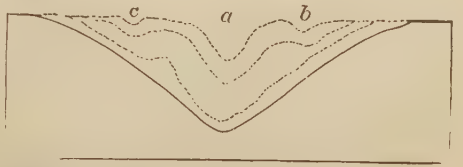


Fig. 213. Diagram illustrating how one gully takes another as a result of lateral erosion.

When a valley has been deepened so that its bottom is below the ground-water surface, ground-water seeps or flows into it, and forms a stream. In Fig. 218, *a* represents the water surface in wet weather, and *b* the water surface in dry weather. The valley whose cross-section is shown by 1 does not have a stream derived from ground-water; the valley 2 has a

Fig. 214. Typical old-field erosion, near Grand Junction, Tennessee. (McGee, U. S. Bureau of Soils.)

small stream in wet weather; while the valley 3 has a permanent stream, because it is below the ground-water level of dry time.

Streams which are fed by lakes, and streams which have their sources in snow- and ice-fields which last from year to year, do not depend on ground-water, though in most cases they receive it.

The deepening of valleys. Swift streams remove material from their beds and so make their valleys deeper, but many slow streams

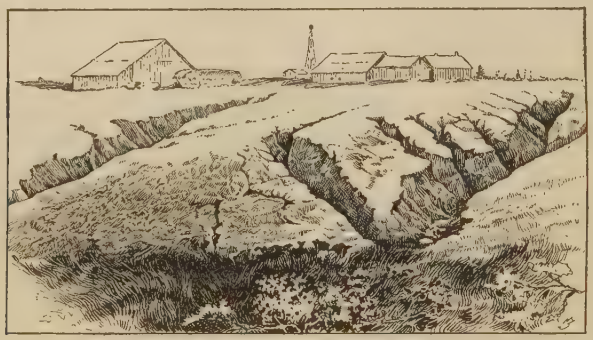


Fig. 215. Gullying in southwestern Iowa. (Iowa State Drainage, Waterways, and Conservation Commission.)

deposit more sediment than they take away, and so make their valleys shallower. Many streams deepen their valleys in their upper courses where their waters are swift, while they make them shallower in their lower courses where the flow is sluggish. As a stream deepens its valley, the gradient becomes less, and the stream flows more and more slowly. In time, every swift stream will cut its channel down until its gradient is low and its current sluggish. A stream cuts the *lower end* of its channel down to about the level of the lake, sea, or river into which it flows, but the channel rises from its lower end to its head. The lowest level to which a stream can reduce its basin is *base-level*.

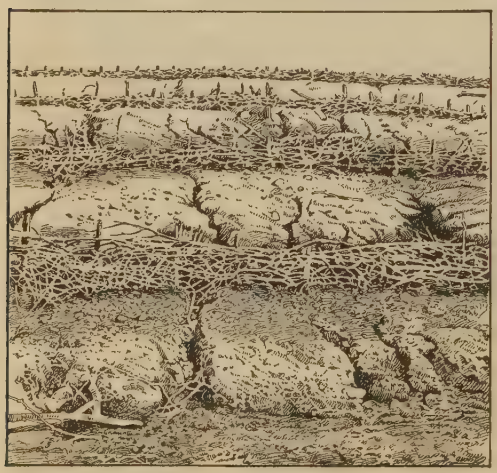


Fig. 216. Brush dams built to check erosion in the southern Appalachians.

The widening of valleys. Valleys are widened in many ways, among them the following: (1) A stream may flow against one side of its channel with such force as to undercut the slope above (Fig. 219). Slow streams are more likely to widen their valleys in this way than swift ones, because they are turned more easily against their banks by obstacles in the channels. (2) Rain-water flowing down the slopes of a valley carries earthy material with it. This widens the valley, by slowly wearing back its slopes. (3) The loose matter which lies on the slopes of a valley creeps slowly downward, especially when wet. It may also *slump* down steep slopes. In these and other ways, all valleys are being widened all the time. At the bases of the slopes of many valleys there is much talus waiting to be carried away by the stream.

Fig. 217. A method of restraining the water of mountain torrents, to prevent the carrying away of the soil. Savoie, France. (Kuss.)

After streams have cut their valleys down to low gradients, they make flats in their bottoms, by side-cutting (Fig. 220). These flats are below the level of the surface in which the valleys lie, and may become very wide. Thus the Mississippi River at Dubuque has a flat between one and two miles wide, and about 600 feet above sea-level. Near St. Louis the flat is 10 miles wide, and about 400 feet above sea-level. At Memphis it is about 35 miles wide, and only 220 feet above the sea. At Vicksburg it has a similar width, and a height of but 90 feet. Normally, valley flats increase in width more or less

regularly down stream (Why?). Figs. 221 and 222 show valley flats of different widths.

The lengthening of valleys. The headward growth of a gully is due chiefly to erosion by the water which flows into its upper end. The head of a gully advances in the direction of greatest wear, and this is rarely in a straight line, for more water flows in at the head, now from one direction, and now from another. Again, the soil or rock in which a gully is cut may be harder at some points than at others, and the head of the gully is likely to advance on that which is worn most easily. Most valleys are therefore crooked from the outset.

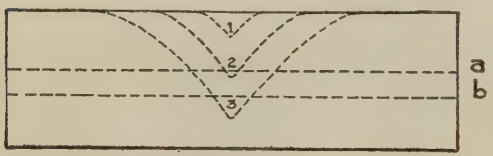


Fig. 218. Diagram showing ground-water surface; *a*, the ground-water surface at ordinary times, and *b*, in times of drought. When a valley has been cut below *a*, there will be a stream in wet weather, but it will go dry in time of drought. When the valley bottom is below *b*, the stream will be permanent.

The headward growth of a valley normally continues until the erosion accomplished by the water flowing into its upper end is equaled by the wear of the water flowing from the same *divide* (water-parting) in the opposite direction. The divide is then permanent (Fig. 223).

Valleys are not all grown-up gullies. Not all valleys were formed by the growth of gullies. A vast area in northern North America, for example, once was covered by a sheet of snow and ice. Most of the rivers which had existed in this area ceased to flow while the ice lay on the land. Many of their valleys were filled, at least in places, by the drift which the ice left when it melted. The result was that great areas were left without well-defined valleys. The melting ice, however, supplied quantities of water, and this flowed along the lowest lines of descent which it could reach, and developed valleys along those lines. Valleys developed by such waters may have permanent streams at the start, since they do not depend on ground-water.

Again, the melting of the ice left many lakes in the hollows of the land it had covered, and the rainfall of the region was great enough to make many of them overflow. When a lake overflows, the out-going water follows the lowest line of descent, and cuts out a valley. In these ways, rivers soon were re-established on the surface from which the ice melted.

Valley and river systems. Most valleys are joined by many smaller tributary valleys. The reason is simple. The erosion of the slopes of valleys by the water flowing from them to the valley-

Fig. 219. The Belle Fourche River undercutting its banks. (Darton, U. S. Geol. Surv.)

bottoms is greater along some lines than others (Why?), and tributary gullies are started, which, growing in the same way as the parent valleys, may come to have permanent streams. These tributary

valleys of the first generation develop branches, and the process may go on until a network of watercourses affects the surface.

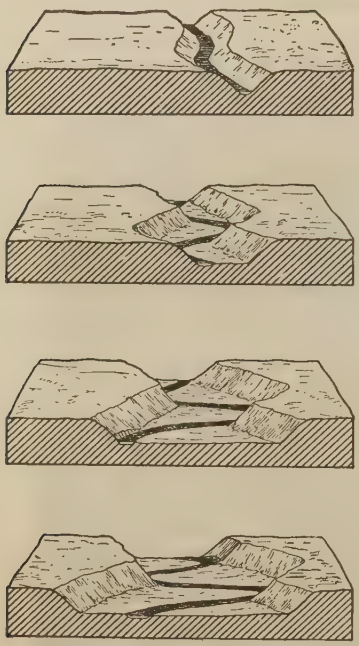


Fig. 220. Diagrams of a river developing a flat by side cutting.

A valley and its tributaries constitute a *valley system.* A stream and its branches form a *river system,* and the area drained by a river system is a *drainage basin.*

Stages in the history of valleys and streams. Valleys grow in size as they advance in years. When a valley is *young,* it is narrow, and its slopes are steep. If the land is high, the valley may have a steep gradient, in which case it soon becomes deep. Its cross-section is then somewhat V-shaped (Fig. 224, 1), and its tributaries are short. A *mature valley* is wider (Fig. 224, 2), its slopes in most cases are gentler (Fig. 225), and its tributaries are longer and older. An *old valley* is wide, and has a broad flat and a low gradient (Fig. 224, 3).

A stream also, as well as its valley, passes from youth to maturity,

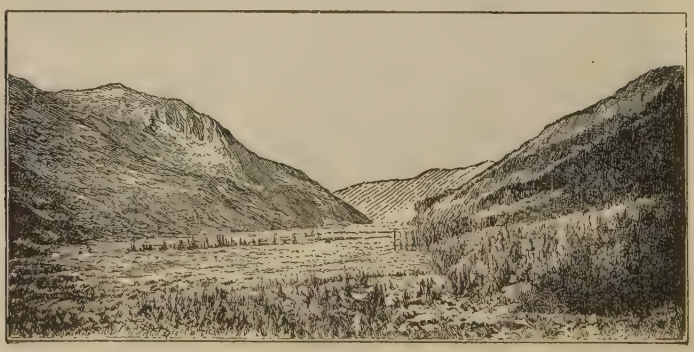


Fig. 221. Gray Copper Gulch, southwestern Colorado.

and from maturity to old age. In its youth, it is likely to be swift, unless it flows through low land. In maturity, it flows less swiftly

Fig. 222. A wide valley flat. Milk River, near the Montana-Alberta boundary. (From photograph by U. S. Geol. Surv.)

and more steadily, and when it reaches old age, it winds slowly through its wide plain. Even an old stream, however, may take on the vigor of youth when in flood.

Fig. 223. Diagram of a divide. The crest of the divide (at A) is permanent if the conditions of erosion are the same on the two sides. Rainfall may lower it, but cannot shift its position horizontally.

The terms *youth*, *maturity*, and *old age* may be applied to river systems as well as to single rivers. Every river system, aided by weathering, has entered on the task of carrying to the sea all the land of its basin which is above base-level. So long as the river system has the larger part of its task before it, it is *young*. When the main valleys have become wide and deep, and the areas of upland have been well dissected by valleys, the river system is said to have reached *maturity*. When the task of reducing its drainage basin to base-

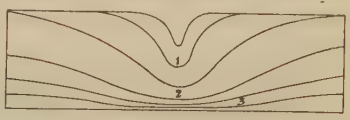


Fig. 224. Diagram showing changes in the shape of a valley as it advances from youth to old age. 1 = youth; 3 = old age. The material in which the valley is cut is all of the same character.

level is nearing completion, the river system has reached *old age*. The main stream of a drainage system attains the characteristics of maturity and old age sooner than its tributaries, and in its lower course sooner than in its upper.

The topography of a drainage basin is *youthful* when its river system is youthful, *mature* when its river system is mature, and *old* when its drainage is old. In an area of *youthful topography*, much of the surface has not yet been much changed by erosion (Fig. 226), and the surface may be ill-drained. In an area of *mature*

Fig. 225. A mature valley slope. Cobb's Creek, near Philadelphia, Pennsylvania.

topography, much of the surface has been reduced to slopes by erosion (Fig. 227), and is well-drained; while an area of *old topography* is one which has been brought down to general flatness by erosion (Fig. 228). Those parts of a drainage basin near the main stream may take on the characteristics of old age, while other parts farther from the trunk stream are not advanced beyond maturity, or even youth.

When an area is worn as low as running water can bring it, it is a *base-level plain*. As streams wear the land toward base-level, they flow on diminishing gradients. Because of this, their velocity and therefore their erosive power decrease constantly. In other words, an area approaches base-level more and more slowly the nearer it gets to it, and it may take as long to wear away the last few feet above base-level as it did all the other hundreds or thousands of feet that once lay above. Few, if any, areas have been absolutely base-leveled. The time required is enormous, and before the task is completed, an area is likely to be elevated with reference

to sea-level, and the quickened rivers started upon the task of again reducing the elevated land to base-level. But many areas have been nearly base-leveled. Such plains are *peneplains* (almost plains). Above their otherwise nearly level surface, occasional elevations may rise abruptly. These elevations, known as *monadnocks* (Fig. 229),

Fig. 226. Diagram of an area in a youthful stage of erosion. The area is some distance from the sea. The bottom of the diagram represents sea-level.

Fig. 227. Diagram showing mature topography in a region situated some distance from the sea. The bottom of the diagram is sea-level. The area shown in Fig. 226 will in time resemble closely the present appearance of this area.

Fig. 228. Diagram showing old topography in a region situated some distance from the sea. The bottom of the diagram is sea-level. Unless the land is elevated, the areas represented in the two preceding figures will finally closely resemble this area.

owe their existence to (1) the greater resistance of their rocks, or (2) a favorable position among drainage lines. The time required for reducing a drainage basin to a base-level plain, is a *cycle of erosion*. As implied above, cycles of erosion commonly are brought to an end by relative uplift of the land before they are completed.

The terms youth, maturity, and old age, as used in geography, apply to *stages of development*, and not to periods of years. Thus a small river, working on soft material, may bring its valley to old age in less time than that required for a large stream, opposed by resistant rocks, to bring its valley to maturity.

Influence of stage of erosion on human activities. The density of population of a region and the condition and activities of its people are influenced greatly by the stage which it has reached in its topographic development. Many young rivers are interrupted by falls and rapids (p. 356) which afford water power for manufacturing, but interrupt or prevent navigation. Many young

Fig. 229. A monadnock on the Canadian peneplain. Tower, Minnesota. (Mead.)

rivers, too, are not available for commerce, partly because they flow in narrow valleys, far below the level of the surrounding country. In parts of western United States, it is also impracticable to lift the waters of such streams to the neighboring uplands for purposes of irrigation. Thus the waters of the Colorado River can be used for irrigation only in the upper part of the river system, or below the Grand Canyon, and the larger irrigation projects of southern Idaho are related definitely to breaks in the walls of the deep canyon of the Snake River. Again, very deep valleys may make travel across their courses almost impossible. In such cases, places where

the valleys can be crossed may have all the significance of mountain passes, controlling the courses of trails and roads. The Denver and Rio Grande Railroad crosses the Green River in eastern Utah where there is a gap in the canyon wall, a gap that earlier determined the course of the Spanish Trail. Roads may run in any direction over young plains whose valleys are shallow. Practically all the land of such plains is available for agriculture, so far as topography is concerned. The poorly drained inter-stream flats may require extensive ditching or tile draining, however, as in parts of Iowa and Illinois.

Where relief is great, the mature stage of erosion is least favorable to most human activities. The larger rivers may be navigable, but most of their tributaries are likely to have steep gradients, with falls and rapids. At this stage, run-off is at a maximum, and streams are most subject to floods. Many of the larger rivers are crossed at occasional ferries and fords, for bridges are hard to maintain. Good sites for river towns also may be few. Wagon roads and railroads follow the narrow ridges between the valleys, or the flats of the larger streams. Farming is difficult on the steep valley slopes, where soils are likely to be thin and easily washed away. In general, the population of such regions is sparse and non-progressive, having little contact with the outside world. Mineral deposits or other special resources may create industrial centers, whose progress serves to emphasize the backwardness of the region as a whole. These conditions are illustrated in parts of the Cumberland and Alleghany plateaus (p. 275).

Old rivers are, as a rule, free from rapids and falls, and in most cases have gradients so gentle that they do not afford good water power. While these conditions favor navigation, the latter may be interfered with by sand bars (p. 364) and the shifting and crooked courses of the channels. It is nearly a thousand miles from Cairo, at the mouth of the Ohio River, to New Orleans by way of the Mississippi River, but only about half as far in a straight line. Much of the land of the broad flood-plains of old rivers is swampy and unavailable until drained, but is then of great fertility (Why?). While floods are most numerous in valleys whose slopes are steep, they are more likely to be disastrous to property on the broad, low flats of older rivers, such as the lower Mississippi (p. 366). On the gentle inter-valley slopes of an old area, the soils are likely to be deep (Why?); their fertility depends chiefly on the character of the underlying rock. The area of arable land is, as a rule, much greater in topo-

graphic old age than in maturity. On peneplains, as on youthful plains of low relief, communication is easy in all directions. Wagon roads and railroads are not confined to certain courses by topography.

Canyons and gorges. Valleys which are narrow and deep are often called *gorges* if small, and *canyons* if large. The Colorado Canyon (Fig. 230) is the greatest canyon known. Its depth is

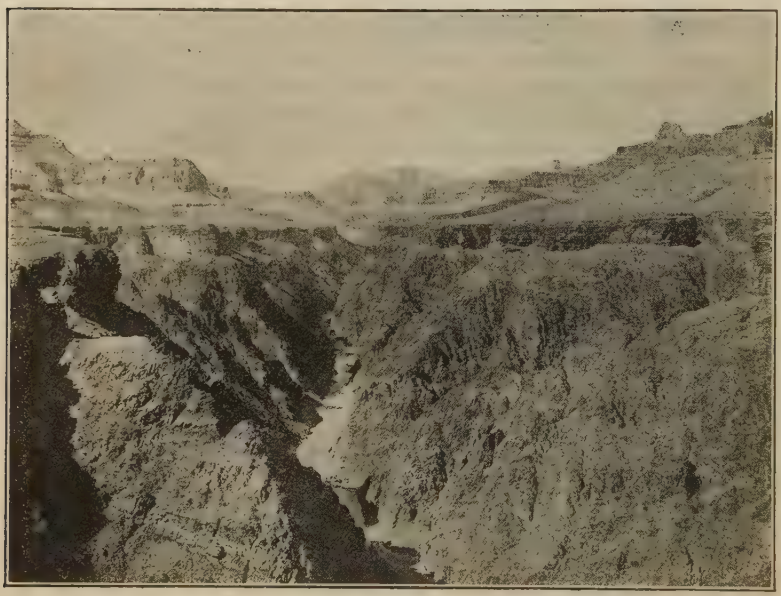


Fig. 230. Inner gorge (canyon) of the Grand Canyon of the Colorado, Arizona. (Walcott, U. S. Geol. Surv.)

about a mile, and it is eight to ten miles wide at the top. Its sides are step-like, because of the unequal hardness of the rock of the canyon walls. The harder strata are the cliff-makers. The Yellowstone (Fig. 231), Snake, and Columbia rivers have wonderful canyons in some parts of their courses, and so has the Arkansas River where it flows through the Rocky Mountains. The canyons of many smaller and less well-known rivers are almost equally striking.

A narrow valley means that the processes which have made it deep have outrun the processes tending to make it wide. Valleys are deepened rapidly when their gradients are high and their

streams strong. They are widened slowly (1) when the climate is arid, so that there is little slope wash, (2) when the stream is so swift that it does not meander, and (3) when the material of the sides is such that it will stand with steep slopes. We conclude, therefore, that (1) great altitude, (2) arid climate, (3) swift streams, and (4) rock which will stand in steep slopes, favor the development

Fig. 231. The canyon of the Yellowstone. (Hillers, U. S. Geol. Surv.)

of canyons. In other words, young valleys in plateaus and mountains (as in western United States) are likely to be canyons. (How can there be large, strong streams in dry regions?)

Some of the ancient cliff-dwellers made their homes in the recesses of canyon walls (Fig. 232), probably because these positions could be defended easily.

Canyons must develop into valleys of another type, for the stream in the canyon will in time cut down to its base-level. The valley will then stop growing deeper, but widening will still go on, and the narrow valley will become so wide that it will cease to be a canyon.

Rapids and falls. The bed of a stream may be steeper at some points than at others, and there the stream flows more rapidly. The quickened flow constitutes a *rapids* (Fig. 233); or, if the water in a stream's bed drops over a cliff, it makes a *waterfall* (Figs. 234 and 135). Waterfalls and rapids are important chiefly because they render the power of the streams available to man for purposes of manufacturing, lighting, transportation, etc. (p. 440). Many electric railroads and many industries depend for power on electricity developed by falls and rapids, and

Fig. 232. Cliff dwellings, southwestern Colorado.

Fig. 233. Rapids in the Kootenay River, British Columbia.

railroads and factories of all sorts are likely to depend on this sort of power still more largely in the future. Rapids and falls interfere with navigation, or prevent it altogether (p. 352).

Waterfalls come into existence in various ways. A river flowing on the high gradient shown in Fig. 235 is likely to be an eroding river. It will wear its channel faster at *A*, where the rocks are soft, than just above, where they are hard, with the result shown in Fig. 236. The continued wear of the water in such a case would cause the rapids at *A* (Fig. 236) to become steeper, and in time the descending water would become a fall (Fig. 237). In this case, *the rapids and falls depend on inequalities of hardness in the bed of the stream.* This is a common way in which falls and rapids originate. A landslide or lava flow may form a dam, over which the water falls or flows in rapids. Most of the waterfalls of the United States are due to glaciation (pp. 393, 405).

Fig. 234. Falls of the Black River, Wisconsin. (Smith, Wis. Geol. Surv.)

Falls and rapids are undergoing constant change, although the change is usually very slow. Many falls are moving slowly up-stream, because the water undermines the hard layer of rock over which it drops (Fig. 237). As a fall recedes, it becomes lower in many cases (Fig. 237). It is clear that such falls will disappear if they recede far enough. If the hard rock over which the water drops is in the position shown in Fig. 238, the fall will not recede, though it will become lower, and will disappear when the stream cuts down to base-level, where

the fall is. (What would be the effect of re-elevation of the basin?) Rapids and falls are temporary features of streams, and, like canyons, are marks of youth. In time, therefore, all existing rapids and waterfalls will disappear.

Narrows. Many valleys are narrow where they cross a tilted layer of hard rock. Such a constriction of a valley is a *narrows*,

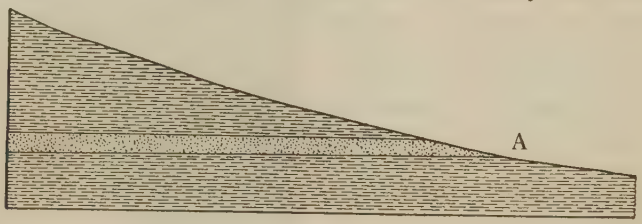


Fig. 235.

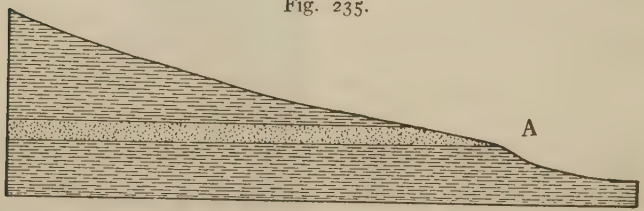


Fig. 236.

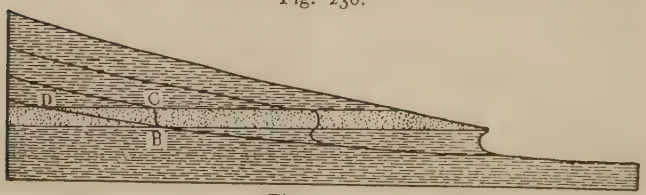


Fig. 237.

Figs. 235, 236, 237. Diagrams to illustrate the development and extinction of a waterfall.

Why will the waterfall cease to retreat up-stream when it reaches C-B, Fig. 237? What changes will occur after it reaches this place?

or *water-gap* (Fig. 239). The Delaware Water-Gap through Kittatinny Mountain (Pa.–N. J.) is a well-known example. Unlike falls, narrows are not most conspicuous in the youth of the stream, but later, after the valley has been much widened except where it crosses the hard rock. Falls are common in horizontal or nearly horizontal beds, but most narrows are developed in tilted beds.

Narrows sometimes serve as gateways through mountains, and

so control lines of travel. The narrows of Wills Creek in Wills Mountain, Maryland, may serve as an example. In the early days of American history, Fort Cumberland was built at this narrows to guard the important pass through the mountains, and Washington's and Braddock's roads ran west through it. At the present time, the Cumberland National Road and an important railway make use of it.

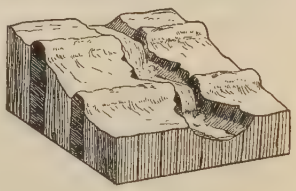


Fig. 238. Diagram of waterfalls developed on vertical beds.

Accidents to streams. Streams are subject to many accidents. If the land through which they flow sinks so that its slope is reduced, they flow less rapidly, or may even cease to flow. If the lower end of a valley sinks below sea-level, the sea-water enters and forms a bay, *drowning* the lower end of the river and its valley. If the streams along a coast end in bays, we infer that the coast has sunk, and that its rivers and valleys have been drowned. Thus Delaware Bay, Chesapeake Bay, and numerous other smaller bays between New York and the Carolinas are drowned valleys.

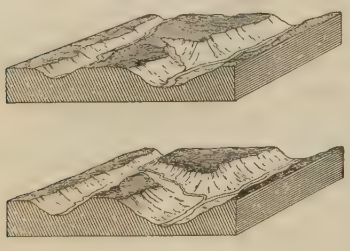
These submerged valleys of the Atlantic coast form part of a great "Inland Waterway" which, interrupted by land in only four

Fig. 239. Lower Narrows of the Baraboo River, Wisconsin. The valley widens beyond the gap, the same as in the foreground.

places, extends from Boston to South Carolina (Fig. 322). An active intercolonial trade was carried on along this route. Parts of it were important in the operations of the Revolutionary War and the War of 1812. Later, canals were constructed between the Raritan and Delaware rivers, between Delaware and Chesapeake bays,

and between the lower Chesapeake Bay and Albemarle Sound (Fig. 317). These canals are all comparatively shallow, and have been of little importance for years. Deep, modern canals probably will replace them in the near future (p. 439).

If the basin of an old stream is raised so that the gradient of the stream becomes greater, its velocity is increased, and it again takes on the characteristics of youth. Such streams are said to be *rejuvenated.*



Figs. 240, 241. Diagrams to illustrate stream piracy.

If by headward growth one valley reaches and enters another where the latter is at a higher level, it may steal the water which otherwise would flow down the higher valley (Figs. 240 and 241). The stream which steals is a *pirate.* The stream stolen is *diverted,* and the stream which has lost its upper water is *beheaded.* Piracy has been rather common among rivers, especially in mountain regions. In the Appalachian region, for example, there are few large streams which have not either increased their waters by piracy, or suffered loss by the piracy of others. Piracy is favored by inequalities of hardness, for streams which do not cross hard rock deepen their channels more readily than those which do (Fig. 242).

When a stream is diverted from a narrows, the water-gap becomes a *wind-gap.* Wind-gaps are common in most mountain regions which have advanced to late maturity. Cumberland Gap, in the southeastern corner of Kentucky, is an example (Fig. 243). It afforded many of the early emigrants the most available route across the mountains, and during the last quarter of the eighteenth century probably more than 300,000 people passed through it to settle in the West. The numerous wind-gaps of the Blue Ridge Mountains figured prominently in the early westward movement of population, and again in the campaigns of the Civil War.

DEPOSITION BY STREAMS

Causes of deposition. Streams may become overloaded in various ways, and so be forced to deposit their excess sediment: (1) Their carrying power may be reduced by a decrease of gradient.

The change may take place suddenly, as at the base of a steep slope, or when a river enters a lake or the sea; or it may take place slowly, as a stream flows through a valley whose slope becomes gradually less. (2) Their carrying power may be diminished by decrease of volume. Streams flowing through arid regions may receive little water, and lose much by evaporation and by absorption into the

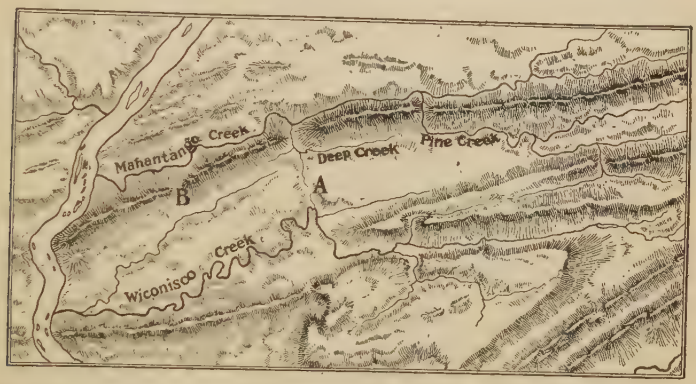


Fig. 242. A case of stream piracy in Pennsylvania. The upper part of the present Wiconisco Creek formerly was tributary to Deep Creek, joining the latter at "A." (From Millersburg and Lykens, Pennsylvania, Sheets, U. S. Geol. Surv.)

What enabled Wiconisco Creek to behead Deep Creek? What was the probable origin of the mountain gap at "B"? Is future piracy likely to occur in this region? Why?

dry earth. Many streams in the West leave the mountains bankfull, to wither and disappear on the lower lands. Many also have much of their water withdrawn for purposes of irrigation. (3) Tributary streams with high gradients may bring to the main streams more sediment than the latter can carry away.

Deposits at the bases of steep slopes. Every shower washes fine sediment down the slopes of hills and mountains, and much of it is left at their bases, where the velocity of the water is checked suddenly. At the lower end of every new-made gully on a hillside, there is a mass of debris which was washed out of the gully itself (Fig. 211). Material in such positions accumulates in the form of an *alluvial cone*, or a gentler sloping *alluvial fan* (Fig. 244). The rivers descending from the Sierras to the valley of California have

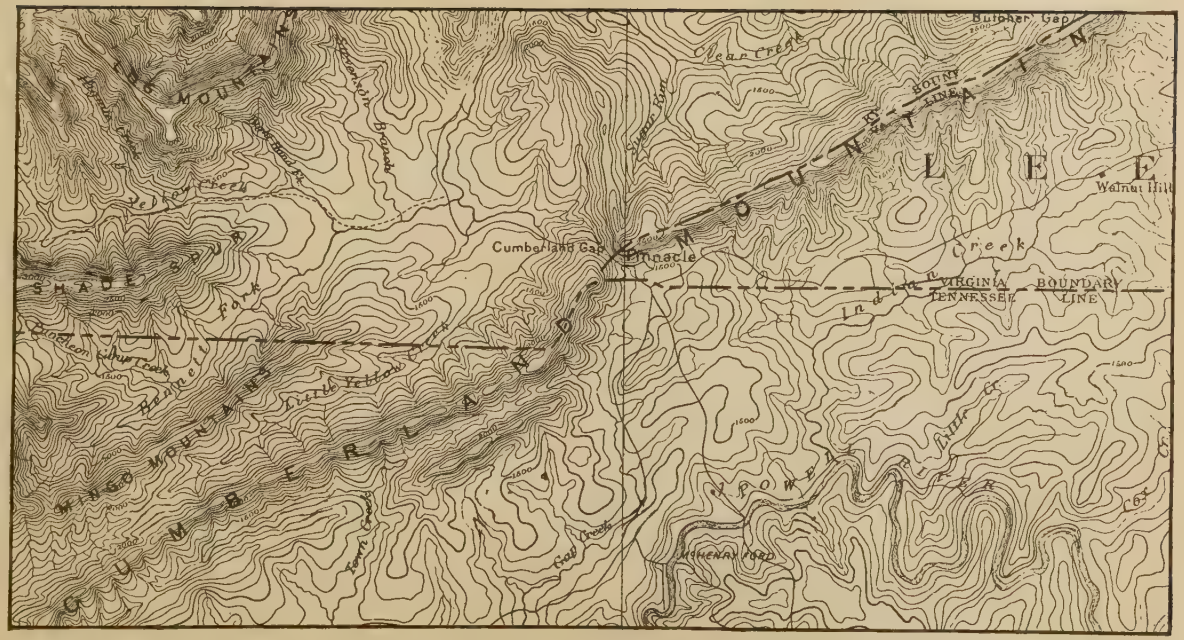


Fig. 243. A topographic map of Cumberland Gap and its surroundings. Scale about 3 miles to the inch. (Cumberland Gap, Md. — Va. — Tenn., Sheet, U. S. Geol. Surv.)

built great fans along the foot of the range, and most of the rivers coming out of the Rockies to the plains east of them have done the same thing. Many of the fans of streams descending from the western mountains are miles across. Fans made by neighboring streams may grow until they unite to form a *compound alluvial fan*, or a *piedmont alluvial plain* (Fig. 245). Such plains exist at the

Fig. 244. Alluvial fan at the mouth of Aztec Gulch, southwestern Colorado. (U. S. Geol. Surv.)

bases of most considerable mountain ranges. Their alluvial deposits may be hundreds of feet thick.

Many alluvial fans and piedmont alluvial plains are valuable for farming. (In general, which would be more valuable, the higher or the lower portions of alluvial fans? Why?) In parts of southern California, for example, such lands are so valuable that farms are very small and highly improved (Fig. 246). Water is supplied (1) by wells, through which the debris of the fan is made to yield up the water it has absorbed, or (2) by irrigating ditches which connect with a stream or reservoir at a greater height. To save more of the flood waters of the Santa Ana River, the principal stream in the citrus fruit region near Los Angeles, provision was made recently for turning a portion of them out of the channel upon the upper

part of the great alluvial fan of the Santa Ana, where, to increase absorption, dikes were thrown up and hundreds of ponds created. Seeping through the porous sand and gravel, this water joins the great artesian reservoir of the region. As a result of this measure and of keeping the artesian wells capped when not in use, the water table of the basin has risen one foot, in spite of the ever increasing demand for water. This means an addition of more than 100,000 acre-feet[1] of water. At half the current price, this amount of water has a value of about $200,000. In many parts of the West, alluvial fans and cones will be used increasingly in the future for the storage of storm-waters. Many villages in mountain valleys are situated on alluvial fans. The agricultural settlements of Utah spread southward from the vicinity of Great Salt Lake along the piedmont alluvial plain at the west base of the Wasatch Mountains. (Why the *west* base of the mountains?) Most of the cities and villages of the state are within this belt.

Fig. 245. Piedmont alluvial plain east of Sierra Nevada Mountains, California. (Fairbanks.)

Deposits in valley bottoms; conditions on flood-plains. The gradient of a stream generally becomes less toward the mouth, and so it happens that sediment is distributed for great distances along valley bottoms. Some of it is left in the channels, and some is spread over the low lands along the streams, making *alluvial plains* (Fig. 247).

Streams sometimes deposit sand bars in their channels (Fig. 248), especially in low water. Bars and the tree trunks and snags which they often catch and hold, interfere with navigation, especially when the rivers are low. In earlier years, many steamboats were wrecked on such obstructions on the Missouri and lower Mississippi rivers. It has been estimated that 70% of all steamboat losses on the Missouri were due to snags. Scarcely was the steamboat established

[1] An acre-foot is water enough to cover one acre to the depth of one foot.

on the western waters before demand was made that the federal government undertake the removal of snags and the dredging of channels. The West had become so powerful a factor in national affairs that it soon obtained the assistance it demanded. In beginning the improvement of western streams, the government accepted the task of fostering internal as well as ocean commerce. In 1824 Congress provided for the first improvements on the lower Mississippi and Ohio rivers. By 1839, 10,000 stumps and snags had been removed from the Ohio alone.

Fig. 246. Cultivated alluvial fan near Riverside, California.

Alluvial plains along large rivers are almost flat, though they slope gently down-stream, and many of them have *natural levees*. This term is applied to the low ridges along the banks of the channel (Fig. 249). In times of flood, the current in the main channel is swift; but so soon as the water spreads beyond its channel, its velocity is checked because its depth suddenly becomes less, and it promptly abandons much of its load. During the period of overflow, the edges of the channel current are checked by the slower moving flood-plain water, and this causes further deposition on the banks of the channel. Repeated deposition in this position gives rise to levees. Embankments have been built by man upon the natural levees of some rivers to prevent the flooding of the valley flats, and to make the bottom lands available for settlement. Louisiana alone has spent

more than $35,000,000 since 1865 in levee building, and is expending now about $800,000 a year in this way. (Why must the protective levees be built higher and higher as time passes?) In spite of such

Fig. 247. A portion of the flood-plain of the Illinois River.

improvements, floods are unfortunately frequent. The damage which they did to buildings, bridges (Figs. 250 and 251), railroads (Fig. 252), etc., in the United States in 1908 was estimated at more

Fig. 248. "Fish hook" sandbar in Little Missouri River, Clark County, Arkansas. (Veatch, U. S. Geol. Surv.)

than $237,000,000, though not all this damage was done on the flood-plains of large rivers. Impressive as this estimate is, it takes no account of the great damage done to the land itself (Fig. 144), nor is it possible to measure the suffering and reduced efficiency of the people living in districts that have been visited by great floods.

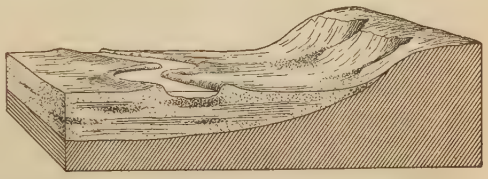


Fig. 249. Diagram showing natural levees.

Most of the early population of Louisiana and Mississippi was distributed in narrow belts along the levees of the Mississippi and its branches. The land here was high enough and dry enough to be cultivated, very fertile, and close to the streams which were the great highways of that time. The plantations were narrow along the streams, and extended back at right angles to them until the land became too low and wet for cultivation.

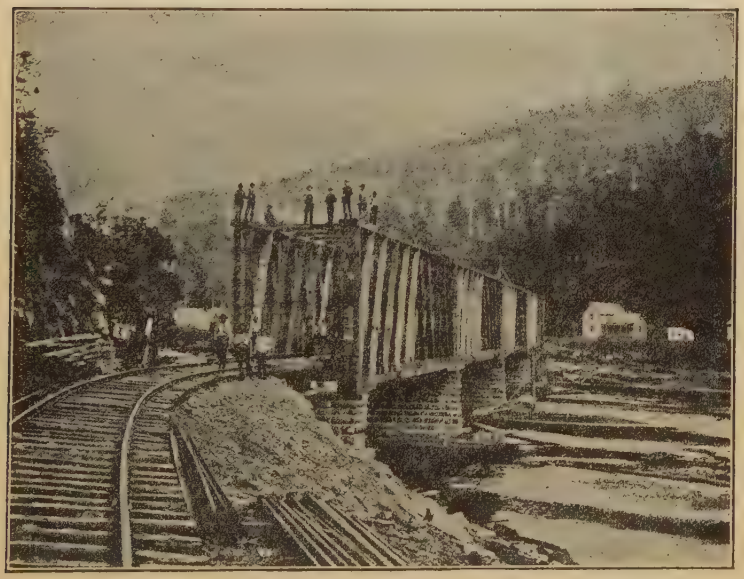


Fig. 250. Railway bridge over the Nolichucky River at Unaka Springs, Tennessee. (Glenn, U. S. Geol. Surv.)

A stream in an alluvial plain is likely to wind about, or *meander* (Fig. 253). This is the result of the low velocity of such a stream, for sluggish streams are turned aside easily. Were such a stream made straight, it would become crooked again, for the banks of all streams are less firm at some places than at others, and the stream

Fig. 251. Same place as shown in Fig. 250 after the bridge and piers were swept away by the flood of May, 1901. (Glenn, U. S. Geol. Surv.)

would cut more at those places. If the shape of the channel were such as to direct a current against a given place in the bank, the result would be the same, even without difference of material. If a curve in the bank is once started, it is increased by the current which is directed into it, and, as the current comes out of a curve, it is projected against the opposite bank, and develops a curve on that side. The water issuing from this curve tends to make another, and so on. Once started, meanders tend to become more and more pronounced (Fig. 254) until, probably in some time of flood, the stream cuts through the neck of the meander and straightens its course.

When a stream has cut off a meander, the abandoned part of the channel may remain for a time unfilled with sediment. If it contains standing water, it becomes the site of an *oxbow lake* or *bayou* (Fig. 253).

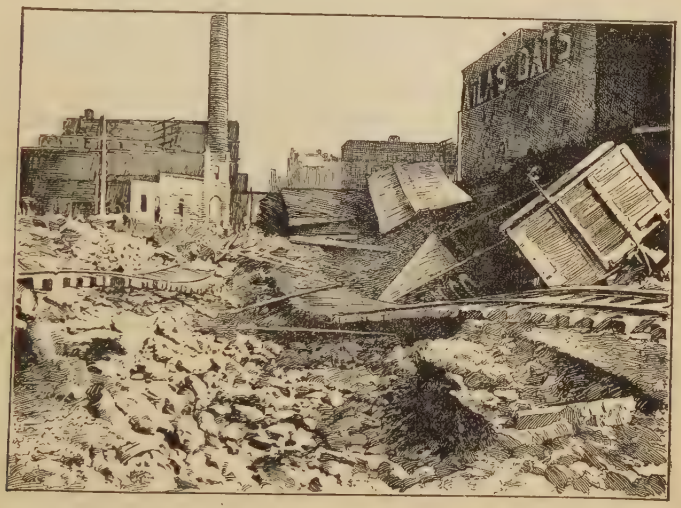


Fig. 252. Scene in freight yards at Kansas City after the flood of 1903. (From photograph by U. S. Weather Bureau.)

The many sloughs, bayous, and swamps of the Mississippi flood-plain interfered greatly with the movements of the Union armies before Vicksburg. Unsuccessful attempts were made by the Northern commanders in 1862 and again in 1863 to straighten the river by cutting a canal between "A" and "B," Fig. 255. Had they succeeded, Vicksburg would have been left on an oxbow lake at some distance from the main channel, and would have lost its control over the river. In 1876, the river itself cut off the meander (Fig. 256), to the great injury of Vicksburg.

Fig. 253. The Rio Grande near Brownsville, Texas.

In meandering, a stream sometimes reaches and undermines the valley bluff, thus widening its valley flat. This is, indeed, the most important process in the widening of valley flats (p. 345). Towns grew up early on the bluffs of the lower Mississippi at points

where the river touched the side of its valley. In this way the location of Natchez, Vicksburg, Memphis, and other places was determined. Such defensible sites, overlooking and dominating the river, were bones of contention between Spain and the United States during the dispute over the southwestern boundary, from 1783 to 1795. The same physiographic features located the Confederate defenses of the Civil War at Columbus (Ky.), Ft. Pillow (Tenn.), Vicksburg (Miss.), Grand Gulf (Miss.), and Port Hudson (La.).

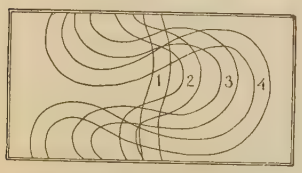


Fig. 254. Diagram showing development of a meander.

By shifting their courses, as the result of deposition and meandering, streams have affected human interests in many other ways. Villages which grew up on the banks of navigable rivers, because of the river trade, in some cases have been left far from the streams by changes in the positions of the latter. Such villages usually

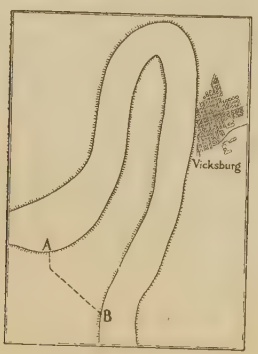


Fig. 255.

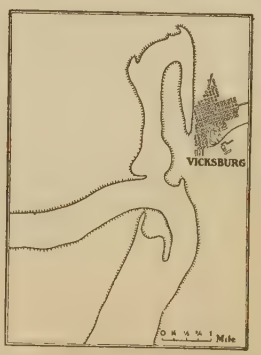


Fig. 256.

Fig. 255. Sketch-map of Mississippi River at Vicksburg at time of Civil War.
Fig. 256. Course of Mississippi River at Vicksburg in 1896.

decline when the streams withdraw their patronage. Other places built on river banks have been preserved at great expense, while some have been washed away. The Mississippi River flows over the site of Kaskaskia, one of the most important French settlements in the upper Mississippi Valley, and the first capital of Illinois. The Missouri River destroyed Franklin, Missouri, an out-

fitting place in the 1820's for the trade across the Great Plains to Santa Fé.

Many streams have been used as boundaries between counties and states. In numerous cases the shifting of the stream has led to boundary disputes, for, by the cutting off of meanders, tracts of land have been shifted from one state to another. In the case of the Missouri River, there have been disputes between Nebraska and South Dakota, Nebraska and Iowa, and Nebraska and Missouri. The Supreme Court finally decided that when the Missouri develops a cut-off, the boundary line does not shift with the river, but remains where it was. Again, many boundaries have been defined as following the "main channels" of streams. Where there are several channels, which is the case in many rivers, the question may arise as to which one is the main channel. Furthermore, the main channel at one time may be a subordinate channel at another time. These conditions have led to disputes over the ownership of islands in different rivers. A curious situation exists where the Menominee River forms the boundary line between Wisconsin and Michigan. This line was fixed along the main channel, and later the question of the ownership of certain islands was found to be involved. Congress provided that Michigan should own the islands above Quinnesec Falls, and Wisconsin those below. But in places below the falls, the main channel, which is defined as the boundary, lies to the west of the islands. In other words, Wisconsin owns islands in Michigan.

The objections to rivers as boundaries are most serious where they form international boundaries. Thus the shifting of the Rio Grande makes it an unsatisfactory boundary between the United States and Mexico. In addition, so much water was diverted from the Rio Grande for irrigation in southern Colorado and New Mexico that there was little water for Mexican farmers below El Paso. Mexico protested to the United States, and finally it was arranged that the United States should construct a great reservoir on the Rio Grande north of El Paso, to regulate and conserve the water of the river, and that Mexico should receive a certain fixed amount of water from this reservoir each year. It may be noted in passing that many of the parallels and meridians which separate counties and states really were fixed by river features. Thus, the southern part of the western boundary of Missouri is a line running *due south from the mouth of the Kansas River,* while the east and west line

which forms the northern boundary of the state was fixed by the falls of the Des Moines River.

Most flood-plains are of great fertility, but many are too wet to be cultivated without drainage. About one-sixth of Arkansas, for example, is swampy, but most of its swamp area is rich alluvial land. When reclaimed, the wet lands of the United States will constitute one of the greatest resources of the nation (p. 459).

Deltas and their relations to man. Where a stream flows into the sea, or into a lake, its current is checked promptly, and

Fig. 257. A delta in a lake. The village is Silva Plana, in the Engadine, Switzerland. (From photograph by Robin.)

soon stopped entirely. Its load therefore is dropped, and if not washed away by waves and currents, makes a *delta* (Fig. 257). That part of a delta above the surface of the water in which it is built is like a flat alluvial fan. Waves and currents may prevent the building of a delta, but otherwise all sediment-bearing streams make deltas where they enter lakes or seas. Deltas may be built where one stream flows into another, especially where a swift stream with much sediment joins a slow one.

Much land has been made by the growth of deltas. Thus the Colorado River has built a great delta many square miles in area at the head of the Gulf of California (Fig. 258). The delta has been built across the gulf near its former upper end, shutting off the head. In the arid climate of the region, this shut-off head became a nearly dry basin, the lowest part of which is about 300 feet below sea-level. The soil being good, water alone was needed to give this area great agricultural value, and the results that have followed the irrigation of parts of it justify its new name, the

"Imperial Valley." Figs, dates, and other tropical products grow here luxuriantly.

In 1906, this low land experienced much trouble. The Colorado River broke out of its banks, and pouring into the basin, made a

Fig. 258. Map showing the delta of the Colorado River and its surroundings.

great lake, called the Salton Sea (or Sink; Fig. 258). The lake spread over farming lands, villages, and railroads, and vast sums of money were expended in turning the water back into its old course.

While rivers have made much delta land, it is to be remembered that the material of which they are composed has been removed from vastly larger areas, and that much of it was rich soil. It is

probable that the loss to man through the removal of such material is far greater than the gain resulting from its deposition.

The deltas of the Mississippi (Fig. 259), the Nile (Fig. 260), and the Hwang-ho (Fig. 261) rivers are among the large and well-known ones. The delta of the Ganges and Brahmaputra has an area (above water) of some 50,000 square miles (nearly as large as Illinois).

When a delta is built in the head of a bay, the outline of the bay determines the shape of the delta. In other situations the normal

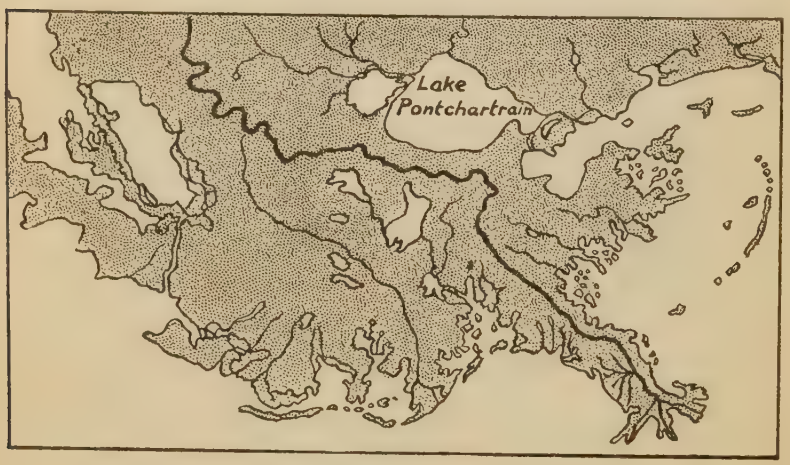


Fig. 259. The lower part of the delta of the Mississippi River.

form of a delta is roughly semi-circular, though there is in many cases a fringe of *delta fingers*, which together have some resemblance to the Greek letter (Δ) which gave these terminal deposits of streams their name. The surfaces of most deltas are nearly flat, and the streams which cross them often give off branches, called *distributaries*, which flow independently to the edge of the delta, and are subject to frequent changes. These changes sometimes affect commerce in a vital way (p. 519). The distributaries of the Mississippi offered the English in the War of 1812, and the Federals in 1862, several possible avenues of approach to the vicinity of New Orleans. The necessity of watching these different lines scattered the men and the resources, and weakened the resistance of

the defenders of the city. By cutting the levees and flooding the lower land, General Jackson was able to increase greatly the difficulties of the English.

Most delta land away from natural levees is low and wet, necessitating diking and drainage before agriculture can be undertaken. The soil of great deltas is deep (What determines its thickness?); in most cases rich in the mineral elements of plant food, for the varied rocks of the entire drainage basin have contributed to it; and fine, for most of the coarse material is dropped farther up river. On the other hand, the material of many small deltas built by swift streams in mountain lakes, is coarse. Some deltas, like that of the Hwang-ho, support dense populations. Delta lands are, however, subject to disastrous floods. It is estimated that the flood of the Hwang-ho River in September, 1887, drowned more than a million people and caused the death of many more by disease and famine afterward. Many villages were destroyed, and hundreds more were submerged temporarily. Previous to 1853, this river had flowed for many years into the Yellow Sea south of the Shantung promontory (Fig. 261). In that year, it shifted its course in flood time, forming a new channel leading northeast into the Gulf of Pechili, 300 miles north of its former mouth. Comparable changes at earlier times, running as far back as 2293 B. C., are recorded in the annals of Chinese history.

Fig. 260. Delta of the Nile River. The dotted area is desert.

Fig. 261. Delta of the Hwang-ho.

Lakes are characteristic features of many large deltas. Some represent former sections of the shifting streams, and some (Fig. 259) are portions of the sea or lake in which the delta is built, portions that were surrounded by the growing deposits or shut in between them and the former shore-line.

Delta cities have peculiar municipal problems, as illustrated by New Orleans. For a long time, inundations were of almost yearly occurrence. In 1849, for example, 220 inhabited squares were flooded and 12,000 people were driven from their homes. Street improvement was difficult; there were no paving stones save those brought as ballast in ships. As late as 1835, only two streets were paved for any considerable distance. On the other streets, car-

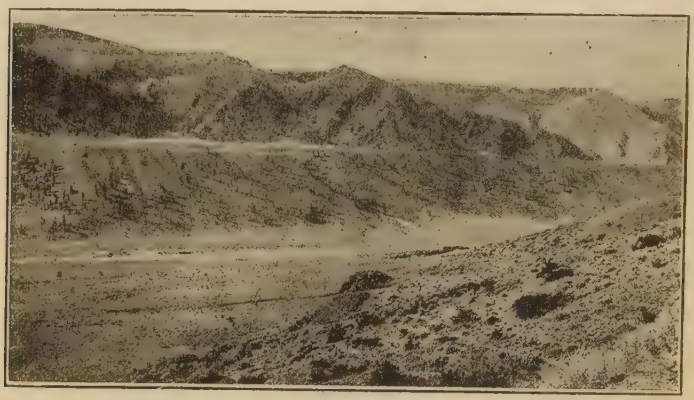


Fig. 262. Terrace of the Columbia River. (Willis.)

riages in wet weather sank to the axle in mire. The question of a domestic water supply was an early and pressing one. The practice of building cisterns to catch the rain-water became general, and the supply still is obtained partly from rains. The city cannot empty its sewage into the Mississippi, for the banks of the river are above the houses. Under these conditions, the city was for years a very unhealthful place.

Alluvial terraces. When a river which has an alluvial flat is rejuvenated (p. 360), the stream sinks its channel below the level of the flat. The remnants of the old flood-plain are then *alluvial terraces*. Such terraces are also formed in other ways. Thus if a stream is supplied for a time with an excess of load, it *aggrades* (builds up) its valley. If, later, the excess of sediment ceases, the stream sets to work to remove that which was temporarily laid aside in its flood-plain (Fig. 262).

The material of many alluvial terraces is gravelly or sandy,

and their soils vary greatly in value. Many towns and cities have had their position determined by alluvial terraces. (What advantages would such locations be likely to have over sites on flood-plains? Sites on the edges of valley bluffs?) The leading towns of the Platte Valley in Nebraska are situated on terraces near the mouths of tributary valleys. (Of what significance is the last fact?) In the middle Illinois Valley, every town is on a terrace, and every terrace has a town. Terrace sites were chosen for most of the first settlements of the Connecticut Valley, such as Hartford, Weathersfield, and Windsor.

Summary. From the physiographic standpoint, the mission of running water is to wear the land to base-level. The material it carries toward and to the sea is prepared for transportation largely by the agents of weathering, and in subordinate amount is worn from the solid rocks by the streams themselves. The irregular wearing down of the land produces most of the familiar relief features of the surface. Their characteristics are determined by several factors, especially by the character and position of the rocks from which they were carved, and the stage of development which they have reached. On its way to the sea, the waste of the land is often laid aside by overloaded streams, forming topographic features subject to later destruction by eroding waters or by other agencies. All phases of river work affect human interests vitally. Much can be done by regulating and controlling streams to increase their usefulness and prevent their doing damage.

QUESTIONS

1. (1) Under what conditions must a valley be deep to have a stream? (2) Under what circumstances may even shallow valleys have permanent streams? (3) In what parts of the United States would you expect to find examples of each type of valley?

2. What are all the conditions which may help to make the flow of streams (1) regular, and (2) irregular?

3. Why do streams carry more and coarser material during floods than at other times?

4. Is the bed of the upper St. Lawrence River being eroded much or little? Why?

5. (1) Why is the rate of erosion in the Colorado Basin so rapid (Fig. 210), especially in view of the fact that a large part of it is in an arid region? (2) Why is the rate in the basin of the Red River of the North relatively so slow (Fig. 210)?

6. Enumerate the various factors upon which the length of life of a waterfall will depend.

7. Why are steep slopes characteristic of arid climates?

8. In what ways may a valley come to have a cross-section like that shown in Fig. 263?

9. What is the age, in terms of erosion, of the area shown in Fig. 143?

Fig. 263. Cross-section of a valley.

10. (1) What is the age, in terms of erosion, of the area shown in profile in Fig. 264? The evidence? (2) To what may the differences in the size of the valleys be due? (3) What changes will occur in the topography of the region in the future?

11. (1) Interpret the contrasted drainage shown by Figs. 265 and 266. (2) In what stage of erosion is the area shown by Fig. 265? (3) Does Fig. 266 indicate the stage of erosion which that area has reached? Why?

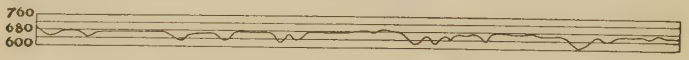
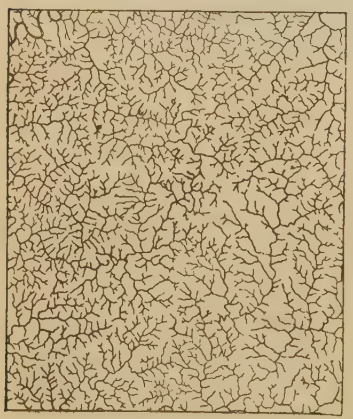
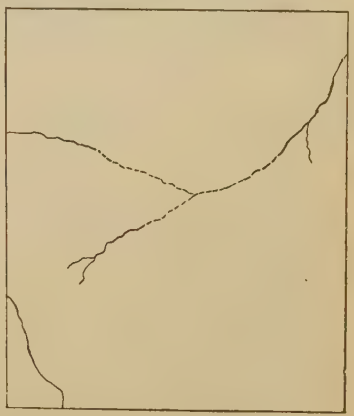


Fig. 264. Profile of an area north of Chicago, near Lake Michigan. Length of section, 4 miles.

12. (1) What topographic features are shown in Fig. 267? (2) Compare and contrast the northern and southern parts of the area as to (a) the climate, (b) the character of the rocks, and (c) the work of the streams.





Figs. 265, 266. Drainage maps of contrasted areas of equal size.

13. In general, what stream-built features are (1) most and (2) least enduring? Why?

14. Enumerate all the important ways in which (1) stream erosion and (2) stream deposition affect human interests.

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Fig. 267.

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See also general texts mentioned on p. 312.

The Work of Ice

Snow is perhaps the most common form of ice, but ice on ponds, lakes, and rivers is familiar to all who live where the winters are cold. In middle latitudes the water in the soil and rocks freezes in winter, often to a depth of several feet. In some parts of the world, too, there are glaciers. In most of its forms ice has some effect on the surface of the land.

Ice on lakes and rivers. Most lakes and rivers in middle latitudes are frozen over for several months each year. This is in some cases a great disadvantage from the standpoint of commerce. The upper Mississippi River is closed to navigation for more than four months of the year. The Illinois and Michigan Canal, connecting Lake Michigan with the Illinois River, was open to navigation, on the average, only 237 days each year between 1848 and 1902. The open season on the upper Great Lakes lasts for only about seven months. The St. Lawrence River is closed by ice for five months each year, and is difficult to enter during another month. Hudson Bay and its tributary rivers are closed even longer. It was a great disadvantage to the French colonies of interior Canada that they were shut off completely from the mother country for nearly half the year, and it is a serious disadvantage to Canada today that her two main gateways from the Atlantic Ocean are closed so much of the time. The inland waterways of England and France are open throughout normal years; those of Germany and central Russia are closed more often, and for longer times as one goes east; and those of northern Russia are closed for five or six months. (Why these differences? Why are the waterways of western Europe so in contrast with those of North America in corresponding latitudes?)

In some cases, the ice of rivers and lakes serves a good purpose. Fishing villages formerly were established on the ice in such places as Saginaw Bay, and are still common in the gulfs of Bothnia and Finland. When frozen over, many northern rivers serve as roadways for local business. Under the influence of Lake Champlain and the Richelieu River, the people of western Vermont for years had much closer relations with Canada than with the rest of New England. After midwinter, when Lake Champlain had become a plain of ice, long trains of sleighs went to Montreal with loads of produce to exchange for merchandise or money. The Alaskan rivers and those of Siberia also are much used for travel when cov-

ered with ice. The harvesting and packing of ice for sale during the ensuing summer is an important industry on many lakes and rivers in northern United States.

When river ice breaks up in the spring, stones and bowlders to which it was frozen in the banks may be floated down-stream for miles. Again, masses of river ice may gather in vast "jams" behind dams or bridges, and the latter may be swept away. The jams themselves form an obstruction, holding back the water and causing floods above. When a jam breaks, the water above may sweep down the valley with destructive violence.

Ice on the sea. In high latitudes ice forms on the sea where the water is shallow, and in polar regions it becomes several feet deep, even on the open sea. Sea-ice is broken up in the summer, and the floating pieces are called *floe-ice*. When the floes are crowded together, they make *ice-packs*, some of which are hundreds of miles across. Ice-packs are one of the obstacles to polar navigation, and make most of the north coast of Russia and Siberia useless even in summer.

The closure of ocean harbors and of seas connected with the ocean, like the closure of inland waters, is a matter of great importance to commerce. The North Sea has a tremendous advantage over the Baltic Sea in this regard. The shores of the latter are hampered by ice each winter, while those of the former are edged with ice only during the most severe weather. The key to Russian expansion since the days of Peter the Great has been the attempt to secure ice-free harbors.

Ice beneath the surface. The wedge-work of ice in the cracks of rock has been mentioned (p. 261). Since a freezing temperature occurs during some part of the year over more than half the earth, the total effect of the freezing of water in the pores and crevices of rock must be great in long periods of time. Water freezing in the soil sometimes "heaves" (displaces) walls if they do not go below the depth of freezing, and it sometimes "works up" stones and bowlders through the soil. Frozen water in the soil has a protective effect also. It makes the soil solid for the time being, and so retards or prevents erosion by wind and water. On the other hand, if heavy rains fall, or if much snow melts quickly while the ground is frozen, floods are increased.

In high latitudes the ground always is frozen below a depth of a few feet (p. 221).

EXISTING GLACIERS

General

Conditions for glaciers. Where the temperature is so low that snow endures from year to year over any considerable area, the snow constitutes a *snow-field* (Fig. 268). Snow-fields occur in mountains in nearly all latitudes, and in polar regions even down to sea-level. Where snow accumulates to great depths and lies long on the surface, it changes to compact ice, and becomes an *ice-field*. The beginning of this change is distinct in the last banks of snow in the spring. Such banks are made up of coarse granules of ice, sometimes

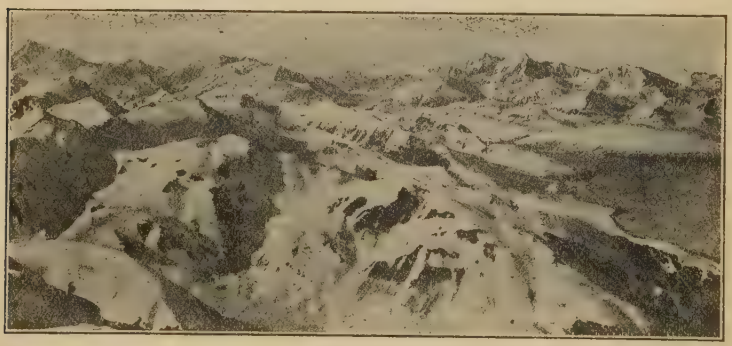

Fig. 268. Snow-fields in Alaska. Russell Fiord at right of view. (Brabazon, Canadian Boundary Commission.)

as large as peas. The change from flakes of snow to granules of ice is due, in part, to the melting of the snow and the re-freezing of the water. If there is much snow, it is compressed by its own weight, and after being compacted in this way, the freezing of the sinking water binds the granules together. When the amount of ice made from snow becomes great enough, it moves out slowly from the place where it was formed to lower and warmer places. When it begins to move, it becomes a *glacier*.

Functions of glaciers. (1) One mission of glaciers is to return to lower and warmer levels moisture which otherwise would be imprisoned indefinitely as snow and ice. (2) Like rivers, glaciers wear the land and move the resulting waste toward the sea. (3) Long after glaciers have melted away, some of their effects on the

conditions of life remain, because of the changes they made in topography, soil, and drainage. Thus past glaciation is a primary factor in the geography of northern United States and northern Europe. (4) Glaciers tend to maintain a relatively uniform volume in the streams which flow from them, and in various mountain regions such streams afford great amounts of power. The "white coal" of Switzerland is probably the greatest natural resource of that country. Electricity developed by water power runs railways, lights cities and villages, supplies power in many mines, and is available to more than two-thirds of the people for various uses. The electric motor is being substituted for manual labor in many of the household industries of Switzerland, and by electricity "grain is being threshed, milk is being churned to butter, water is being pumped, food for the cattle is being prepared, and the farmer is being relieved of his most arduous labor."

Types of glaciers. Glaciers have various forms, depending on the amount of ice and on the shape of the surface beneath and around them. If the snow-field which gives rise to a glacier is at the upper end of a mountain valley, the ice moves down the valley as a *valley glacier* (Fig. 269). In high latitudes, snow-fields and ice-fields may lie on plains or plateaus. When the ice in such situations begins to spread, it moves in all directions from its center. Such glaciers are *ice-caps* or *ice-sheets*. Very large ice-caps sometimes are called *continental glaciers*. The main ice-caps of Antarctica and Greenland (Fig. 270) are large, but small ones are found on various promontories along the coast of Greenland, on Iceland, and on some Arctic islands. Glaciers occur also at the bases of some mountains, being formed by the union of the spreading ends of valley glaciers. Such glaciers are *piedmont glaciers* (Fig. 272). Of these types, valley glaciers are most common and most familiar, but the large ice-caps contain much more ice.

Valley Glaciers

Distribution. The chief regions of valley glaciers are the high mountains of Eurasia, such as the Alps, Caucasus, and Himalayas; the southern Andes; and the higher mountains of northwestern United States and western Canada. In Alaska, lofty mountains near the coast compel the abundant precipitation of moisture brought by westerly winds from the Pacific Ocean. The heavy snowfall on the upper slopes feeds many glaciers, some of which reach the sea.

The glaciers of Switzerland are known best and help to attract thousands of tourists to that country each year. In 1910, Congress created Glacier National Park on the Continental Divide in northwestern Montana (Fig. 359). It is about sixty miles in length and contains more than sixty glaciers. The glacier-fed streams flowing from the park will have great importance in connection with irrigation

Fig. 269. A valley glacier in the Cascade Mountains, Washington. (Willis, U. S. Geol. Surv.)

and the development of water power. The water flowing from some of these glaciers finally reaches Hudson Bay; that from others goes to the Gulf of Mexico; and still others are tributary to the Pacific. This may become one of the best known and most visited of our National Parks, for the mountains and glaciers offer the chance for mountaineering of real Alpine character, the streams abound in trout, and the mountains still shelter enough game animals to become an important game refuge. The park contains one of the most beautiful portions of the Rocky Mountains lying within the United States.

Size. There are nearly 2,000 glaciers in the Alps, only one of which has a length of ten miles. Less than 40 have a length of five miles, while the great majority are less than one mile long. Only a few are so much as a mile wide, and none are more than a few hundred feet thick. Larger glaciers occur in the Caucasus Mountains and in Alaska. Seward Glacier in Alaska is more than 50 miles long, and three miles wide at the narrowest place. The glaciers of western United States south of Alaska are not so large as the larger glaciers of the Alps.

Movement. The ice of a glacier is wasting continually, both by melting and evaporation. In spite of this, many glaciers remain about the same size year after year. This is because the loss by melting is replaced by advance from the snow-fields, from which the ice creeps down the valleys until it reaches a place so warm that the melting at the end balances the forward motion.

Most glaciers move very slowly. Of those whose rate of advance has been measured, few move more than two feet a day, and very few as much as seven. The rate of movement depends chiefly on (1) the thickness of the moving ice, (2) the slope of the surface over which it moves, (3) the slope of the upper surface of the ice, and (4) the topography of its bed. (What combination of conditions would favor most rapid movement?) The exact nature of glacier movement is a disputed question. It was thought formerly that glaciers flowed somewhat as stiff liquids do, but it is very doubtful if the motion is really flowage.

Ice-Caps

As already stated, ice-caps may lie on plains or plateaus, and may be large or small.

The area of Greenland has been estimated variously at from 400,000 to 600,000 square miles, and all but its borders is buried beneath one vast field of ice and snow (Fig. 270). Except on a narrow border of a mile or so at the edge of the ice-sheet, not even a bowlder or a pebble relieves the great expanse of white.

The thickness of the Greenland ice is not known, but, where thickest, it is probably thousands of feet. Near its margin the ice is much crevassed, but the interior is comparatively smooth so far as known. The ice of this great field is creeping slowly outward. The rate of movement never has been measured, and is probably not the same at all points, but it has been estimated not to exceed a

foot a week. This ice-cap is, in one sense, more of a desert than the Sahara, since it is inhabited even less than the latter.

Where the edge of the Greenland ice-cap lies a few miles back from the coast, the rock plateau outside it has numerous valleys leading down to the sea. Where the edge of the ice-cap reaches the heads of these valleys, ice moves down them, making valley glaciers. Many of the latter reach the sea, where their ends are broken off and float away as icebergs. This is the source of most of the bergs (Fig. 271) seen from steamers which cross the North Atlantic. Some are so large that they float far to the south before they are melted. Since they are sometimes surrounded by fog, they may be a menace to navigation.

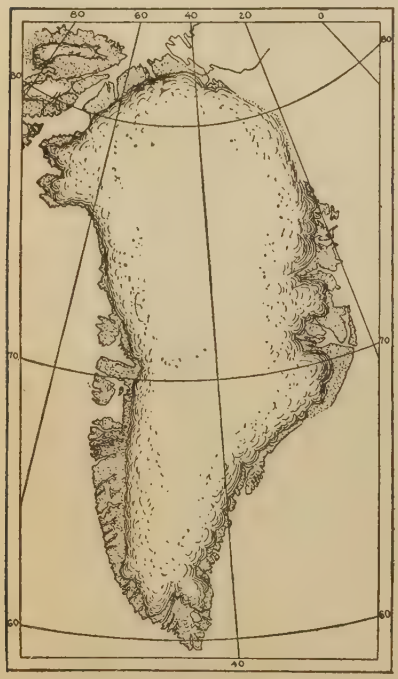

Fig. 270. Map of Greenland ice-sheet.

The Antarctic snow-and-ice-cap is far more extensive than that of Greenland, but its area is not so well known. It is probably several million square miles in extent, and the thickness of its ice probably exceeds that of Greenland. The ice descends to the sea at many points (p. 218), and huge blocks of it become icebergs.

Piedmont Glaciers

A number of alpine glaciers come down adjacent valleys in the St. Elias range of Alaska, and spread out on a low plain at its base. So much do their ends spread that they unite to form a single body of ice, 70 miles long and 20 to 25 miles wide, called the *Malaspina Glacier* (Fig. 272). Its area is greater than that of Delaware. Its central portion is free from debris, but is interrupted by thousands of deep, wide cracks. A belt along the margin of the glacier five miles or less in width is covered by rocky and earthy debris, and parts of it are clothed with vegetation. The under-

growth is here so thick that travelers have to cut paths, and on the edge of the ice there are trees three feet in diameter. Another large but unexplored glacier of the same type lies a few miles west of the Malaspina, and others occur about North Greenland.

Fig. 271. An iceberg.

ANCIENT GLACIERS

There have been times when glaciers were much more extensive than now, for various features produced only by glaciation (pp. 391–405) are found in many places that are now free from ice. The latest of these periods is known as the *Glacial Period*. In this country, glaciers existed even in the mountains of New Mexico, Arizona, and Nevada. The amount of ice in the glaciers of Utah or Colorado was then far greater than all that now exists in the United States south of Alaska. At the same time, a great area east of the Cordilleran

Fig. 272. The Malaspina Glacier, and numerous valley glaciers. (Model by Martin; copyright by University of Wisconsin.)

mountain system, some 4,000,000 square miles in extent (Fig. 273), and lying partly in Canada and partly in the United States, was covered with an ice-sheet.

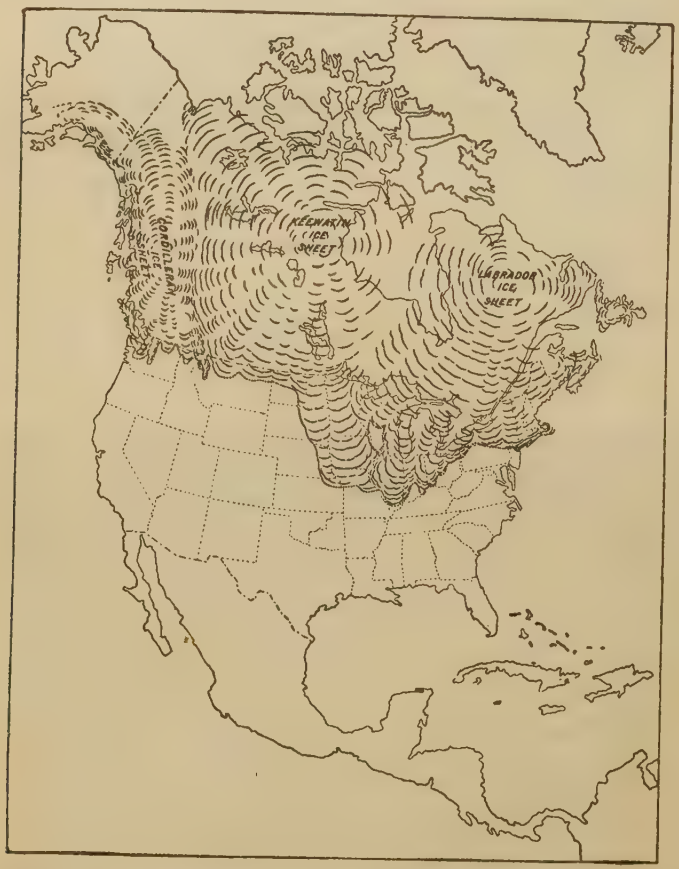

Fig. 273. Sketch-map showing the area in North America covered by ice at the stage of maximum glaciation. (Chamberlin.)

The ice-sheet of North America originated in two principal centers, one on either side of Hudson Bay. The beginning of each was doubtless a great snow-field. At first these snow-and-ice fields grew by the addition of snow, and later also by the spread of the ice to

which the snow gave rise. The two ice-sheets finally became one by growing together. This great continental glacier did not originate in mountains, but on high plains, where the topography had been shaped mainly by river erosion.

When largest, this ice-sheet covered all New England, northern New Jersey and Pennsylvania, and much of Ohio and Indiana. Its edge crossed the Ohio River where Cincinnati stands, and advanced a few miles into Kentucky. Farther west it reached almost to the southern end of Illinois. Its edge crossed the Mississippi near St. Louis, and followed, in a general way, the course of the Missouri River to western Montana. Most of the continent north of this line was covered with snow and ice, but there was an area of 8,000 to 10,000 square miles, mainly in southwestern Wisconsin, over which the ice did not spread. This is known as the *driftless area*, because there are no ice deposits in it. In the Cordilleran mountains there was also a great body of ice which remained somewhat distinct from that which spread from the other centers.

There was extensive glaciation in Europe at about the same time as in North America. The glaciers of the Alps were then many times as large as those of to-day. On the south they extended quite beyond the mountain valleys, and spread out on the plains of northern Italy, where they left their deposits. Similar conditions existed in the other mountains of Europe where glaciers now exist, and in some where glaciers are not now present. There was also a large ice-sheet in Europe (Fig. 274), but its area was only about half that of the ice-sheet of North America. The principal center from which the ice spread was the mountains of Scandinavia.

Great ice-sheets are not known to have developed in other continents during the Glacial Period, but their valley glaciers were very large.

The history of the continental glaciers was complex, both in Europe and in North America. After the growth of the first great North American ice-sheet, it shrank to small size, or disappeared altogether. Then followed a relatively warm period, when plants and animals lived in the region abandoned by the ice. Another continental ice-sheet then developed, spreading over the region from which the first had melted, and extending still farther south. As it advanced, the second ice-sheet in places buried the soil which had formed on the drift left by the ice of the first epoch. Such soils, here and there with the remains of plants which grew in them, are

one means by which it is known that there was more than one ice-sheet. A third, fourth, and fifth ice-sheet, each somewhat smaller than its predecessor, developed and disappeared. In other words, there were several epochs when ice-sheets were extensive, separated by epochs when they were much smaller, or when they had disappeared altogether. The ice-sheets of Europe had a similar history.

Cause of the glacial epochs. The development of the great ice-sheets was due to a change in climate, and especially to a reduc-

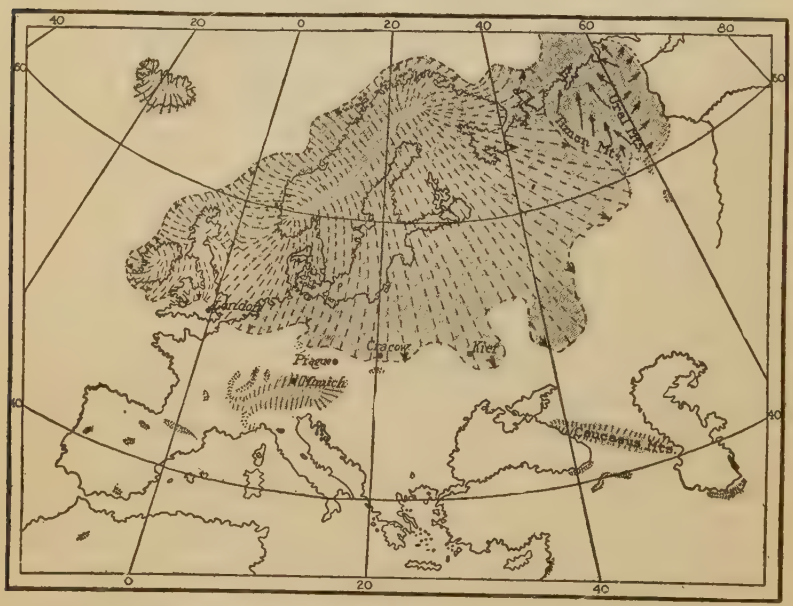

Fig. 274. Sketch-map showing the area of Europe covered by the continental glacier at the time of its maximum development. (James Geikie.)

tion of temperature. The cause of the cold is not known, though many explanations have been suggested. One is that the northern lands were raised to great heights. Another is based on changes in the shape of the earth's orbit, and on changes in the direction of the earth's axis. The hypothesis which seems most acceptable is that the change of climate was due to a change in the constitution of the atmosphere. An increase in the amounts of carbon dioxide and water vapor would make the climate warmer, while a decrease

in these things would make it colder. Good reasons have been suggested for variations in the amounts of these substances in the air, and also for the heavy precipitation in the regions where the

Fig. 275. Glaciated surface of limestone. The view shows also the relation of drift to the bed-rock beneath. Kelleys Island, Ohio. (Stauffer.)

ice-sheets existed. Heavy snowfall is as necessary as low temperature for extensive glaciation.

CHANGES DUE TO GLACIAL EROSION

How glaciers erode. Clean ice, moving over smooth, solid rock, would erode little, but ice carrying pieces of rock in its under layers wears the surface, even when the latter is smooth and solid. Like wind and water, therefore, ice erodes by means of the rock tools which it carries. The bottom of a glacier secures tools in various ways. (1) As a snow-field accumulates, it may lie upon an uneven

surface covered with loose pieces of rock. These are covered and enclosed by the snow, and when the latter becomes ice and begins to move, they are carried along with it. A glacier, therefore, has tools from the outset. (2) As a glacier creeps out over surfaces covered with soil, it becomes united to the ice in the soil, in part by the freezing of descending water. Further movement of the glacier causes some of the soil to be carried forward.

The loose material removed by a glacier from the surface is used to wear the bed-rock farther on. Each kind of tool does

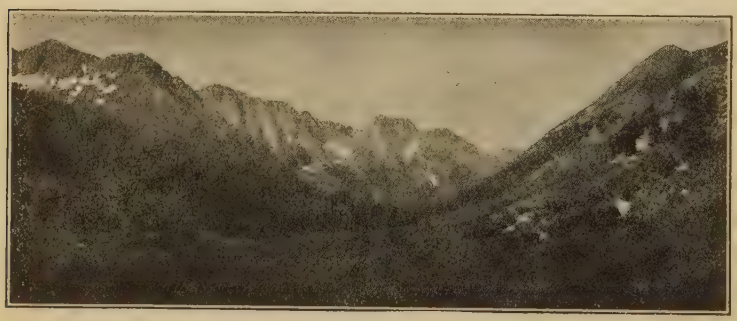

Fig. 276. Glacial trough in San Juan Mountains, Colorado.

its appropriate work. Fine, earthy material in the bottom of the ice polishes the rock below, while sand and small pebbles make scratches (*striæ*) upon it. Grooves are made by bowlders held in the bottom of the ice and urged along under great pressure. Meanwhile the tools are themselves polished, scratched, and worn smaller and smaller. The finest products of the grinding have been called *rock flour*. Polished and striated bed-rock surfaces (Fig. 275) are among the clearest marks of the former existence of glaciers in many places now free from ice.

Changes in valleys. Mountain valleys through which glaciers pass are widened and deepened, and their walls made smoother (Figs. 276 and 277). In many cases the heads of glaciated valleys are big, blunt, and steep-sided. Most of the lakes which add so much to mountain scenery are (1) in rock basins gouged out of valley floors by glaciers (Fig. 277), or (2) behind dams formed by the deposits of the ice (Fig. 278). Tributary valleys commonly join their main valleys at the level of the latter, but the bottoms of many valleys

that were deepened and widened by former glaciers are much (in some cases 500 to 1,000 feet) lower than the lower ends of their tributaries. In such cases streams descend in rapids or falls from the tributary *hanging valleys* (Fig. 279). Much water power is afforded by such rapids and falls in the western mountains.

The ancient ice-sheet overrode hills and divides as well as valleys. In many cases the ice deepened the valleys more than it lowered

Fig. 277. A valley in the Needle Mountains, Colorado, cleared of all earth and loose rock by a glacier which once passed through it. The moving ice also smoothed all the projecting points of rock.

the hills, and where this was true, it increased the *relief*, even though it reduced the *roughness* of the surface.

Elevations reduced and changed in shape. Hills overridden by ice-sheets are worn down and smoothed off, and the wear is greatest on the side of the hill against which the ice moves (Fig. 280). Many small elevations were worn away entirely by the continental glaciers.

Ice-shaped coasts. Glaciers which descend into the sea through bays tend to gouge out the bay-bottoms, and to wear back the bay-heads. If such glaciers melt away, the sea enters to form long,

narrow, steep-walled re-entrants, called *fiords*. Norway (Fig. 281), Scotland, Maine, and Alaska have fiord coasts, though all of them owe their characteristics in part to sinking. Many islands front these coasts, most of them representing elevations of the old land whose surroundings have been drowned.

Fig. 278. Convict Lake, east base of Sierra Nevada Mountains, California. The lake is formed by a morainic dam. (Fairbanks.)

GLACIAL DEPOSITS

General characteristics. Most of the material transported by a glacier is carried in its lower part; but some is carried in the ice above its bottom, and some on top of the ice. All of it is left, finally, on the surface of the land. The materials deposited by glaciers, called *glacial drift* or *till*, range from finest earth to huge bowlders many feet in diameter

Fig. 279. Hanging valley on south side of Nunatak Fiord, Alaska. (Tarr, U. S. Geol. Surv.)

(Figs. 282 and 283). They are not stratified, and are so deposited in many places as to form distinctive topographic features. Much of the drift deposited by the continental glaciers is a thorough

mixture of many kinds of material, for it was derived from a vast area within which practically all kinds of rocks occur. (Compare these features with those of stream deposits.)

Leading types. When the end of a valley glacier or the edge of an ice-cap stays in the same place for a long time, a thick body of drift is lodged beneath it, for drift is brought to this position continually by the oncoming ice, and left there. Such a deposit is a *terminal moraine* (Fig. 284). All the other drift deposited by an ice-sheet is *ground moraine*. After a glacier melts, the area of ground moraine is not as great as the glaciated area, for glaciers do not carry debris in all parts of their bottoms. In general, the drift is thickest and covers the

Fig. 280. A hill smoothed by the glacier ice which overrode it. Shore of North Greenland. (From photograph by Chamberlin.)

Fig. 281. The Sogne Fiord, coast of Norway. (Robin.)

largest proportion of the surface near the margins of a glaciated area, and is thinnest and least continuous in the region from which the ice spread (Why?). For this reason, there are large areas of bare rock and of thin, bowlder-strewn soil on the uplands of eastern and northeastern Canada. Together with a bleak climate, these conditions render large areas unfit for agriculture. Much of the material removed by the ice from Canada was deposited in the United States.

The ice of a valley glacier moves toward either side of the valley, as well as down-valley, and as it spreads sidewise from the center, it shifts debris from the axis of the valley to the edge of the ice on either side. The *lateral moraines* left along the sides of a valley after the ice is gone (Fig. 285) are composed chiefly of this material, but partly also of the debris that composed the lateral moraines which were on the glacier (Fig. 286). The lateral moraines left in valleys are hundreds of feet high in many cases, and more than a thousand feet high in some.

Fig. 282. Section of unstratified drift near Henry, Illinois. (Crane.)

Surface features. Because glaciers distribute their drift very unevenly, large areas once covered by ice are marked by hillocks, mounds, and ridges, and by basin-like or trough-like depressions. These features are most pronounced in terminal moraines, the surfaces of which may be distinctly rough and hummocky (Fig. 287). In typical ground moraines hills are lower, basins shallower, and slopes gentler.

Fig. 283. A glacial bowlder near Hibbing, Minnesota. (Van Cleef.)

In the Lake States, the rougher parts of the terminal moraines commonly are used for woodlots and pastures (p. 275), for the surface is too uneven and the soil too coarse and stony to be cultivated successfully, in competition with the neigh-

boring prairies. Many of the hollows in the surface of the drift contain lakes (p. 399), ponds, and marshes (p. 458). It is estimated that there are 4½ million acres of marsh land in Minnesota, nearly

Fig. 284. A glacier in the Cascade Mountains, Washington. Shows spreading end of glacier, crevasses in ice, and terminal moraine. (Willis, U. S. Geol. Surv.)

as much in Michigan, and 2½ million in Wisconsin. The total swamp area for the three states is larger than the combined area of Massachusetts, Connecticut, Rhode Island, and Delaware. Nearly all this swamp land is the result of glaciation.

The surface of the drift is very unlike that developed by the

erosion of running water, for in the latter the depressions have outlets, and the hills and ridges stand in a definite relation to the valleys.

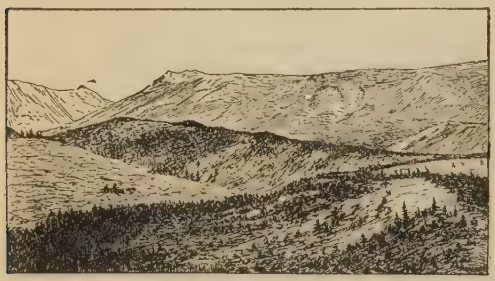

Fig. 285. A lateral moraine left by a former glacier in the Bighorn Mountains of Wyoming. (From photograph by Blackwelder.)

The drift left by the continental glacier increased the relief in some places (Fig. 288), with unfavorable results; but in most places it decreased relief and left the surface less rough than it found it (Fig. 289). This made it easier to cultivate the land and to build roads. Most of the surface between the Ohio River and the Great Lakes appears to have been made smoother. But for glaciation, much of this region probably would have a maturely eroded surface, not unlike that of the driftless area, and a poorer soil than it now has.

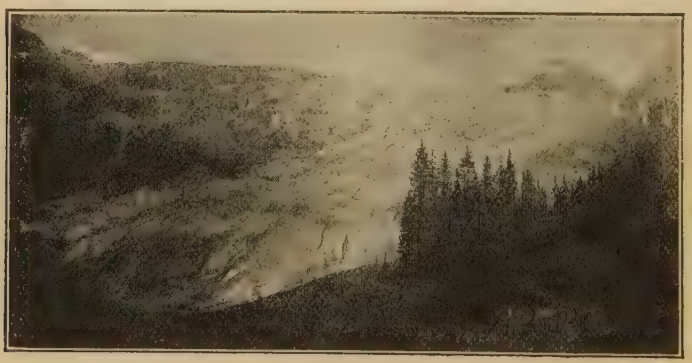

Fig. 286. The Illecillewaet Glacier, British Columbia.

Deposits beyond the land. Glaciers which descend into the sea may build submarine banks and even islands. Along the eastern coast of North America, these deposits may have reached the edge of the continental shelf in some places. Martha's Vineyard, Nantucket, and Long Island are composed largely of drift. The shel-

tered waterway behind Long Island facilitated the development of maritime interests in southern New England. Indeed, Long Island

Fig. 287. Terminal moraine topography near Oconomowoc, Wisconsin. (Fenneman.)

Sound is said to have been "the most powerful single factor controlling the destiny of New England."

Glacial lakes. The thousands of lakes in northern United States (Fig. 290) and Canada are nearly all of glacial origin. Some are in basins gouged out of the bed-rock (Fig. 291); some are in the unfilled portions of drift-choked preglacial valleys; and many are in hollows in the surface of the drift (Fig. 292). The terminal moraines of many valley glaciers form dams, ponding the waters of the streams above, making lakes (Fig. 293). The

Fig. 288.

Fig. 289.

Fig. 288. Diagram showing how a nearly level surface may be replaced by a rough one through the uneven deposition of drift.

Fig. 289. Diagram showing how glacial drift may replace a hilly surface with a comparatively level one.

smaller and shallower of these lakes and ponds are being destroyed rapidly by (1) the sediment washed into them from the tributary

Fig. 290. Map showing the abundance of lakes in parts of the glaciated area. (From Barrett, Minnesota, Sheet, U. S. Geol. Surv.)

slopes, and (2) vegetable matter (Fig. 294). Some are being drained slowly (Why slowly?) by the erosion of their outlets. In the future, many of the shallower ones will be drained by man, that he may use their bottoms as farm land. It has been estimated that there are 8,000 lakes, big and little, in Minnesota, and that half of them will be destroyed by natural processes within fifty years. Connecticut has been credited with having had some 4,000 lakes at the close of the Glacial Period; 2,500 of them have been obliterated, and the sites of many of them now form choice garden spots. In southern Michigan and Wisconsin many early settlers located their farms on the bottoms of former lakes, attracted by the flat land and the fine, easily-worked soil.

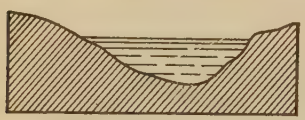

Fig. 291. Section of a lake in an ice-scoured rock basin.

292. Section of a lake lying in a hollow in the surface of the drift.

Fig. 293. Section of a lake behind a barrier of drift.

Deposits of *marl* occur in and about many glacial lakes. Marl is a soft, limey earth, the calcium carbonate of which is contributed chiefly by the shells of fresh-water mollusks and by lime-secreting

lake plants. In parts of Michigan and northern Indiana, these deposits are utilized in making Portland cement.

The lakes and swamps of the glaciated region make the streams flow more steadily through the year, by holding back some of the water of wet times, letting it flow out in times of drought. The drift itself exerts a similar influence, for, on the whole, it is thicker than the mantle rock of other regions, and therefore absorbs more

Fig. 294. A pond in Yellowstone Park nearly destroyed by encroaching vegetation. (Fairbanks.)

water, which it yields up slowly, making the supply of ground-water to streams more steady than it would be otherwise. Thus floods are less numerous and less dangerous, and the value of the streams for navigation and power is increased. By reducing or preventing floods, the porous drift and the lakes also greatly reduce soil erosion.

Certain lakes which came into existence along the margin of the continental glacier disappeared with the ice. One of the largest of the marginal lakes (*Lake Agassiz*) lay in the valley of the Red River of the North (Fig. 295). This lake covered a maximum area of about 110,000 square miles, an area greater than that of all the Great Lakes. The water, however, was shallow. It came into existence when the edge of the retreating ice lay north of the lake, and blocked drainage in that direction. The water rose in the basin until it overflowed to the south, finally reaching the Mississippi

River. When the ice at the north melted back far enough, a new and lower outlet was opened to Hudson Bay, and the lake was drained. Lake Winnipeg and several smaller lakes may be regarded as remnants of Lake Agassiz, for they occupy the deepest parts of the old basin.

As late as 1870 the floor of extinct Lake Agassiz was practically unoccupied by farmers (Fig. 296), but during the next few years

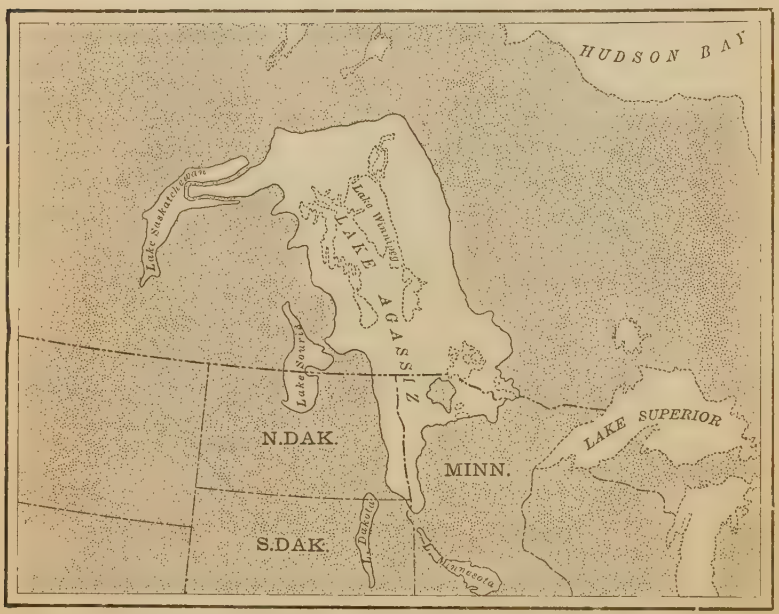

Fig. 295. Map of extinct Lake Agassiz, and other glacial lakes. Lake Winnipeg occupies a part of the basin of Lake Agassiz. (U. S. Geol. Surv.)

its soil was found to produce a fine grade of hard wheat, and a great tide of farm-seekers turned to the region (Fig. 297). On the nearly level lake floor it was possible to plow league-long furrows in straight lines, and later to do much of the work by such labor saving machines as the steam plow. Ft. Gary quickly grew into the city of Winnipeg, and the wheat of the region helped to make Minneapolis the leading flour manufacturing city of the United States (p. 441).

The Great Lakes were larger than now after the ice had retreated

north of their basins, but while it still covered the lower St. Lawrence Valley. A part of their history, dating from the time when the last ice-sheet was waning, is suggested by Figs. 298 to 301. These lakes did not exist, so far as known, before the Glacial Period, but river valleys probably extended along their longer diameters. Lake basins were developed as a result of (1) the deepening of these valleys by ice erosion, (2) the building up of the rims of the basins by the

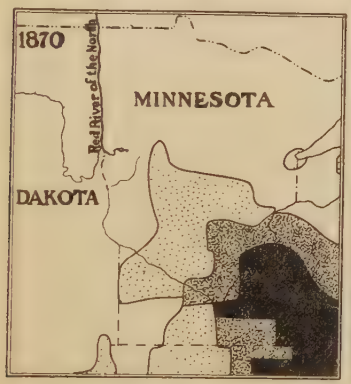

Fig. 296.

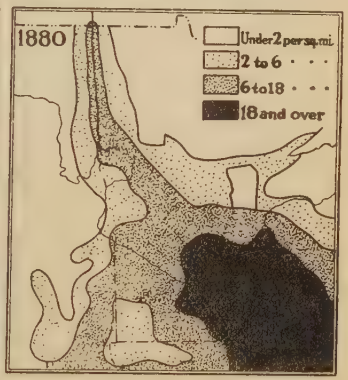

Fig. 297.

Fig. 296. Map showing distribution of population in region of Red River of the North in 1870.

Fig. 297. Population map of region of Red River of the North in 1880.

deposition of drift, and perhaps (3) the down-warping of the sites of the basins. The influence of the Great Lakes on climate and on certain industries has been noted (pp. 79, 117, 145). Their importance as commercial highways is considered in Chapter XVI.

Hundreds of the glacial lakes are of great benefit to man as pleasure and health resorts, and as sources of water supply. Many have become famous through their fine summer residences, and very many more are visited by numerous camping, boating, and fishing parties. In these ways the lakes have become large factors for good in the life of the people.

The Iowa Waterways and Conservation Commission recently declared, with reference to the few lakes of that state, that the state government is "under evident obligation to care for them, to keep them as a trust for the people, and to see that they are not only not abused and rightly used, but to see to it that they are used with such wisdom, in all the resources they afford, as to be constantly more and more serviceable and valuable in every way."

Fig. 298. The beginning of the Great Lakes. The ice still occupied the larger parts of the present lake basins. (After Taylor and Leverett, U. S. Geol. Surv.)

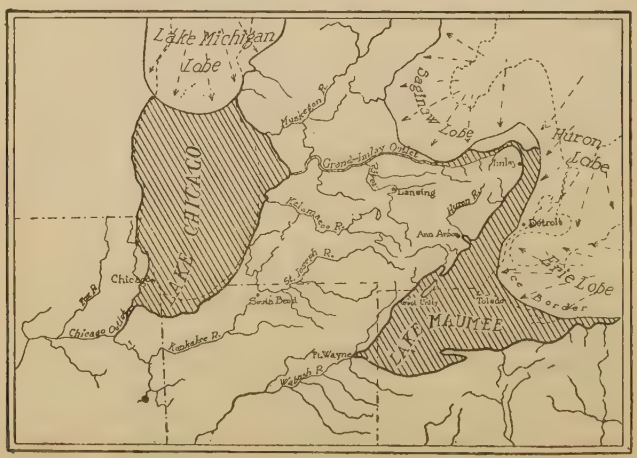

Fig. 299. A later stage in the development of lakes Chicago and Maumee. The ice has retreated, and the outlet of Lake Maumee is being shifted. (U. S. Geol. Surv.)

Effect of ice deposits on stream courses. The deposition of drift deranged the rivers. After the ice melted, the surface drainage followed the lowest lines open to it; but these lines did not always correspond with the former valleys, for some of the latter had been filled, and most of them were blocked up in some places. The surface waters therefore followed former valleys in some cases,

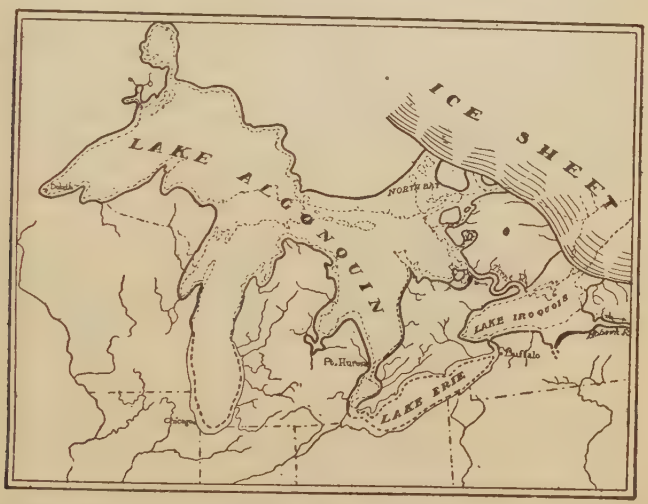

Fig. 300. The Great Lakes at the Algonquin-Iroquois stage. The outlet to the sea is by way of the Mohawk Valley. (Taylor.)

and in others flowed where there had been no valleys. In choosing their new courses, the streams in places ran down steep slopes or fell over cliffs. Many of the rapids and falls of the glaciated area, so important in the economic life of the country (p. 440), came into existence in this way.

Glacial soils. In the United States, glaciation increased the amount of mantle rock, and improved the quality of the soil in many places. Much of the latter is good because it is a thorough mixture of material derived from many kinds of rock, and so is well supplied with all the mineral elements necessary for plants (p. 270). In Illinois, the average productivity of the soils developed on the youngest drift sheet is greater than that of the soils of the older drift. (Suggest plausible reasons for this.) It is instructive to

compare Fig. 402, showing the relation of the improved acreage to the total farm acreage in the different states, with the map showing the glaciated area (Fig. 273). Iowa, Illinois, Indiana, and Ohio are seen to lead in the relative amount of their improved land. Glaciation is perhaps the most important fact in the geography of each of these states, and it has greatly furthered their high rank in agriculture.

The benefits which the states between the Ohio River and the Great Lakes received from glaciation may be illustrated further.

Fig. 301. A still later stage of the Great Lakes. The sea is thought to have covered the area shaded by lines at the east. (Taylor.)

Fig. 302 shows the glaciated and unglaciated portions of Ohio. The unglaciated part belongs to the Alleghany Plateau. It is in a mature stage of erosion, and the thin, sandy soils on the steep slopes wash easily. The first settlement in Ohio was made in this part of the state, at Marietta; but soon the tide of settlement set toward the more attractive glacial plains farther west and north, and the population of most of the unglaciated counties remained relatively sparse until the mineral resources of the region were developed. Many farmers in the unglaciated section turned their attention to sheep-

raising when they found they could not grow grain for export in competition with the glaciated farms, and grazing was long an important industry in the southeastern part of the state.

About four-fifths of Indiana were glaciated. On the average, the glaciated land is worth about twice as much as the unglaciated, and the yields of staple crops bear a similar relation. The southern boundary of the region within which 4,500 bushels of corn are grown per square mile, is the margin of the latest drift sheet. The situation is much the same in Illinois. Fig. 303 shows the yield of corn (the leading crop) throughout the state. The relations of the yield to the several sheets of drift, whose borders are indicated by the irregular, heavy lines, are striking. The low yield of the unglaciated areas at the extreme south and northwest is noteworthy.

Fig. 302. Map showing the glaciated (shaded) and unglaciated portions of Ohio.

The quality of the soil in some places was injured by glaciation. In some places the drift is very thin, while in others it is very stony (Fig. 150), so that great labor is necessary to put it in workable condition. Again, the drift may be too sandy or gravelly to make good soil, or its surface may be too rough (pp. 275, 396).

Special uses of glacial deposits. Much drift clay (rock flour) is used for making brick, tile, and other clay products. Ohio has been the leading state in the clay industry for many years, because of the abundance of raw clay, part of which is drift, cheap near-by fuel, excellent shipping facilities, and nearness to great markets. About 1,000,000,000 bricks are made from glacial clay each year in the vicinity of Chicago. The gravel of the drift is used extensively for road making, and in the manufacture of various kinds of cements.

DEPOSITS BY GLACIAL WATERS

Water flows in abundance from all glaciers in the summer, and from many glaciers all the time. Stream work, therefore, accom-

panies glaciation in all cases, and much of the drift left by ice is modified by water afterward.

Streams which flow from glaciers carry so much sediment that in many cases they build gravelly or sandy plains beyond the ice. Such a deposit in a valley below a glacier is a *valley train*. Valley trains are developed best just outside terminal moraines. The Rock River, in southern Wisconsin, filled its valley with gravel and sand to a depth of 300 to 400 feet just outside the terminal moraine of the last glacial epoch. The Columbia River filled its valley, locally, to the depth of 700 feet with sediment washed out from the ice. Since the ice-sheet melted, parts of most of the valley trains have been carried away, and their remnants are terraces (Fig. 262). Drift terraces are common features of many of the valleys of south-flowing rivers in the glaciated area and just south of it.

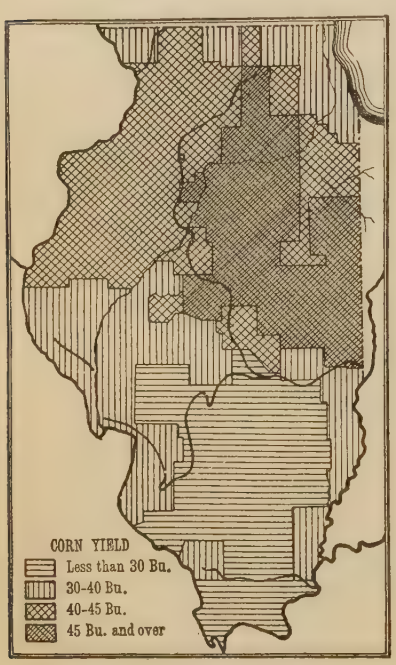

Fig. 303. Map showing average yield of corn per acre throughout Illinois.

Streams which issue from an ice-sheet and fail to find valleys build alluvial fans. By growth, these fans may unite, making an *outwash plain*, very much like a compound alluvial fan. Like valley trains, outwash plains are developed best just outside the terminal moraines of ice-sheets, and their materials are stratified. East New York, Woodhaven, Jamaica, and other suburbs of Brooklyn grew up on the outwash plain of Long Island before the terminal moraine just to the north was much settled. (What were the probable reasons for this?)

Deltas may be built in lakes at the ends or edges of glaciers, and the deposits made by waters beneath the ice and at its edge take on locally the form of ridges and hillocks.

As a glacier melts away, the waters produced by the melting flow over the surface of the drift which the ice had deposited, and modify it more or less by eroding in some places and depositing in others. As a result of all these phases of water work, much of the drift is stratified.

EFFECTS OF ANCIENT ICE-SHEETS ON LIFE

The continental ice-sheets caused extensive changes in the life and the life relations of higher latitudes. The development of the first great ice-sheet in our continent, for example, killed all plant life over the millions of square miles which the ice covered, and drove all animal life from the region. Most of the types of plants which had grown in the north before the Glacial Period probably continued to live, but they lived farther south.

Though a tree or a shrub cannot migrate, a given type of tree or shrub may migrate through its seeds. In the course of many generations, Arctic plants migrated southward in front of the edge of the slowly-advancing ice-sheet, while those that had lived in middle latitudes were driven still farther toward the equator.

Animals, moving more freely than plants, were able to migrate as individuals. As the ice-sheets grew, the animals of the north doubtless crowded southward. This migration from the north into middle latitudes drove the animals of the latter still farther south. If similar changes were taking place in the southern hemisphere, as seems probable, there was a tendency to crowd life into low latitudes from both sides, and no parts of the continents, not covered by ice, were free from the effects of migration and crowding. Animal life migrated from North America to South America by way of Central America and the Isthmus of Panama, and corresponding migrations affected the eastern hemisphere. The lessening of the area of land on which animals and plants could live must have decreased greatly the total amount of plant and animal life on the earth.

When the first ice-sheet melted, the area left bare was again peopled by plants and animals moving poleward from lower latitudes. The time necessary for the melting of an ice-sheet was perhaps as long as the time necessary for its growth — many thousands, probably many tens of thousands of years — so that the redistribution of animals and plants over the area which had been glaciated, was slow. Before the drift left by the ice was covered with vegetation, the blowing of dust must have been very extensive,

and the surface must have been subject to much greater erosion than now by water.

As the ice receded northward, the Arctic plants which had been driven south followed it; but in mountainous regions, some moved up the mountains instead of moving northward. Thus it came about that plants whose ancestors lived in Arctic regions are now found high in the mountains of middle latitudes. They probably lived in the lowlands of these latitudes during the glacial epoch, and found the colder temperatures to which they are adapted higher up on the mountains, as the climate again became warmer.

The life of the sea was affected similarly, though perhaps less extensively than that of the land. The northern waters must have been distinctly colder than now.

Each glacial epoch in turn produced similar effects, so that the Glacial Period was one of great importance to all life.

Summary. Although less important, ice takes its place with air and water as one of the three agents which modify land surfaces. From this standpoint, its principal mission is the wearing of the land and the moving of the waste toward the sea. Through their widespread effects on topography, soil, drainage, and the distribution of plant and animal life, the ancient ice-sheets are far more important than the glaciers of to-day, as factors in human affairs. Existing glaciers are valuable to man chiefly in connection with the development of power on the streams which flow from them.

QUESTIONS

1. In northern United States and Canada, would floods which occur as the river ice breaks up in spring be more likely to be disastrous on north-flowing or south-flowing streams? Why?

2. Why are there more glaciers in the Sierra Nevada and Cascade mountains than in the Rocky Mountains? Why are there more in Montana than in Colorado?

3. Enumerate all the factors which may influence the size of a given valley glacier.

4. Compare and contrast typical topographies due to (1) glaciation and (2) river erosion.

5. (1) What are all the important ways in which human interests have been (a) benefited and (b) injured by the work of the ancient ice-sheets in the United States? (2) *On the whole*, was glaciation beneficial or injurious?

6. Why are the effects of glaciation more favorable, from the standpoint of man, in northern United States than in northeastern Canada?

7. (1) What are the *possible* ways in which the topography shown by Fig. 304 may have originated? (2) Which is the *most probable* way? Why? (3) How could you settle the matter in the field?

Fig. 304. View on Staten Island. (Willis, U. S. Geol. Surv.)

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Many of the topics of this chapter are discussed at greater length in standard textbooks of physiography and geology. (See p. 312.)

CHAPTER XVI

THE USES AND PROBLEMS OF INLAND WATERS

Many ways in which streams and lakes affect human interests have been noted in preceding pages. In the present chapter, inland waters are considered from the standpoints of navigation, power, irrigation, drainage, and water supply.

Navigation

In the early development of many countries, lack of roads led to the use of the waterways for trade and travel. Even after roads and turnpikes had been provided, water transportation was, in general, much cheaper, and traffic continued to use waterways where they were available. A horse that could draw one ton on a good road in a cart could draw thirty to forty tons in a canal boat. In the United States, the average cost of hauling a ton a mile over roads is now about twenty-three cents. At this rate, it costs the farmer more per bushel to haul wheat 10 miles to a railroad than it costs the buyer to ship it from New York to Liverpool.

Where railroads have come into competition with waterways, the latter in most cases have lost much of their traffic. The waterways of some countries have been protected by legislation from ruinous railroad competition, and certain waterways, for example the Great Lakes, furnish such favorable conditions for transportation that their traffic has grown in spite of railroad competition. The average cost of hauling over the railroads in the United States declined from $7\frac{1}{3}$ cents a ton per mile in 1837, to less than $\frac{4}{5}$ of a cent a mile in 1905; yet under favorable conditions, the cost of transportation by water is estimated to be only $\frac{1}{4}$ to $\frac{1}{3}$ that by rail. In 1909, rates for iron ore on the Great Lakes were less than one mill a ton per mile, while the rates for ore by rail were about one cent a ton for the same distance.

RIVER NAVIGATION

Streams the first waterways used systematically. Naturally, streams were the first waterways to be used systematically for commerce (Why?). The Euphrates was one of the rivers to which men first entrusted themselves and their goods. Sculpturing on the Assyrian monuments shows that the first boats had frames of light wood, covered with skins. These boats could not ascend against the strong current, and therefore were used only for down-river trade. They were broken up on the lower river, the wood sold, and the skins carried by asses on the return journey. There was also very early traffic on the Nile River.

After a time, river navigation led to coastwise navigation, but to the end of the Mediæval Period there was little or no navigation of the open ocean. It is only in the Modern Period that open sea navigation has permitted the development of world commerce and an "oceanic civilization."

Leading rivers of other countries. Because of its relief (p. 41), few of the rivers of Asia are important highways of commerce. The Yang-tze is the greatest highway. Fed by the snow-fields of the mountains of Tibet, and flowing to the Pacific through some of the most densely populated provinces of China, it is both one of the longest rivers in the world, and one of the most important commercially. Large ocean steamers ascend 600 miles to Hankow; smaller steamers navigate the river 500 miles farther, to the mouth of the gorges; and native junks go up many miles more into the rich province of Sze-chuan. The Yang-tze is the greatest highway between western and eastern China. The Hwang-ho, the other great river of China, flows through a densely settled region, but is nearly useless for navigation because of its shifting and silt-choked channel.

In India, the Ganges and Indus present a contrast similar to that of the Yang-tze and Hwang-ho. The Ganges traverses the most populous and wealthy provinces, and has been of great significance throughout the history of India. It is fed by many Himalayan torrents, and flows for about 1,200 miles across the alluvial plains of the north. Ocean steamships ascend the Hugli, one of the mouths of the Ganges, to Calcutta, and, though it has suffered from railroad competition, the river is used more or less for navigation to Hardwar, at the base of the mountains. The Indus River is used but little by steamers, because of many sand bars and frequent

changes in the channel. Together with its larger tributaries, it is valuable chiefly for irrigation. The great rivers of Siberia are navigable for hundreds of miles, but lose in commercial importance because they flow to the Arctic Ocean.

The relief of Africa limits the navigation of most of its rivers to relatively short distances (p. 41). The Nile has regular steamboat service to the First Cataract, but navigation is not easy in the delta portion of the river below Cairo. Above the cataracts, the river is navigable throughout the year for long distances.

Throughout the history of Russia its rivers have been its chief highways. Even to-day, they have greater relative importance than the rivers of western Europe, because other means of transportation are less satisfactory; wagon roads are poor and railroads few. Most of the Russian rivers rise in the vicinity of the Valdai Hills and follow long courses across low, nearly level plains. Their currents, therefore, ordinarily are gentle. They are navigable throughout most of their courses, and it has been possible to connect the different systems by canals, so that there is water connection between the Caspian, Black, Baltic, and White seas. While the above conditions are favorable to commerce, navigation of the Russian rivers is attended by serious drawbacks. They are ice-locked in winter (p. 380), subject to great floods when the snows melt in spring, affected by sand bars which hinder navigation at low stages, and most of them are tributary to inland seas. The Volga is the most important Russian river, and the largest river of Europe. Together with its tributaries, it is said to afford 7,500 miles of navigation. Its usefulness is lessened by the fact that it flows in its lower course through a semi-arid region, and ends in a land-locked sea.

Most of the larger rivers of central and western Europe are important commercially, and large sums have been spent to improve them, and extend their connections by canals. In the last fifty years not less than $1,000,000,000 have been expended in France, Belgium, Holland, Germany, Austria-Hungary, and Italy, in an area smaller than the part of the United States east of the Mississippi River. In Germany, river transportation increased more than five-fold in the thirty years preceding 1905, in spite of the fact that Germany has a greater railroad mileage than any other country in Europe. This is in striking contrast with the situation in the United States (p. 425). The rivers and canals of Germany (p. 437) furnish from 8,000 to 10,000 miles of navigable water-

ways. So much work has been done in dredging, straightening, and otherwise improving the larger rivers, that it is said scarcely one of them flows in a natural channel.

The Rhine has influenced the history of Germany more than any other river, and is to-day the most important commercial river in Europe. Fed by melting snows in Switzerland and regulated in volume by its passage through Lake Constance, it flows through western Germany and the Netherlands, into the North Sea. Rotterdam, on the Rhine delta, is one of the greatest ports of continental Europe, and Cologne, though far inland, is practically a seaport. The fertile valley of the Rhine is settled densely, and probably there are more important cities on its banks than on an equal length of any other river. The Elbe is commercially the second river of Germany, though much less important than the Rhine. The traffic on these rivers is largely in heavy freight, such as coal and grain. (Why are the cities on the lower courses of the German rivers flowing into the Baltic Sea less important than those situated similarly on the rivers flowing into the North Sea? Is this difference likely to continue?)

The Danube River has been an important highway since early times. Like many other delta-building rivers, it was difficult to enter until jetties were built at its mouth. Extensive improvements have been made also at the "Iron Gate," and elsewhere. The Rhone is the largest river of France, and its valley is the natural highway into the country from the south. Navigation in the delta portion of the stream was impeded by shallow and shifting channels, and canals have been constructed from the sea to the river near the head of the delta. Though large sums have been spent in these and other improvements, the Rhone is not navigable for large ships. The Po and the Ebro are the only other European streams of importance emptying into the Mediterranean, and neither is used much for navigation.

In Great Britain, the rivers are comparatively short, but their value is enhanced by the fact that their lower courses are drowned, and subject to rather high tides. The tides help to make Liverpool and London great seaports, though both are on small rivers. Like the United States, great Britain has neglected, till recently, the question of waterway improvement, in part because of the nearness of ocean transportation, the expense of canal construction, and the influence of the railroads. To-day transportation in England is said to be the most expensive in Europe.

The Amazon is the largest river in the world, with a length of about 4,000 miles. Ocean steamers can ascend it for 1,000 miles, and with its 29 large tributaries it furnishes more than 20,000 miles of navigable water, most of it through dense forests. The river is used in getting out tropical woods, rubber, and other products. The Orinoco is navigable to within 100 miles of Bogota, and the La Plata system is navigable for long distances, especially for light-draft boats.

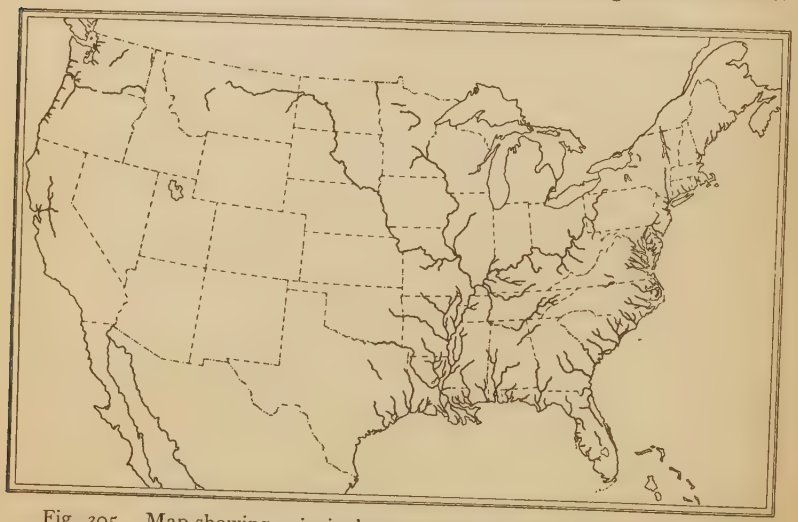

Fig. 305. Map showing principal streams in the United States actually used for purposes of transportation (1906). Only the sections so used appear on the map. (Data from map by U. S. Bureau of Corporations.)

Besides the great rivers mentioned above, there are many others which serve as highways of trade and travel that it is not practicable to consider here.

Navigable streams of the United States. There are about 300 streams in the United States that are navigated more or less (Fig. 305). They have a combined navigable length of about 26,400 miles — more than the circumference of the earth. Only a few now have much commercial importance, and many are frequented only by small boats engaged in local trade. As Fig. 305 shows, most of the navigable streams are in the eastern half of the country. The absence of navigable waterways (Why absent?) has been a serious disadvantage to much of the West.

The principal rivers, and the part which they have played in the development and commerce of the country, are discussed briefly in the following paragraphs. Most attention is given to the Mississippi System, because it is by far the most important.

Atlantic Rivers of United States

On the Atlantic slope there are nearly 150 streams navigable for varying distances from the sea — in most cases to the head of tide-water. The rivers of New England are navigable for short distances only, because of falls and rapids.

The Connecticut is navigable 50 miles, to Hartford; the Merrimac 17 miles, to Haverhill; the Saco 5 miles, to Saco and Biddeford; the Androscoggin 30 miles; the Kennebec 44 miles, to Augusta; and the Penobscot 60 miles, to Bangor. All these cities receive much freight by water. Many streams of central and northern New England are used for rafting lumber and floating logs.

Although the streams of New England afford little navigation, the larger valleys have been important highways since the settlement of the region began. They guided fur traders, lumbermen, and farmers (p. 340) into the interior. They served as lines of advance and retreat for numerous Indian war parties and colonial armies. General Arnold invaded Canada in 1775 by way of the Kennebec and Chaudière valleys. To-day, many of the valleys are followed by railroads. Since the rivers could not serve as highways far inland, the colonial authorities provided promptly for the opening of roads. Partly for the same reason, the main lines of the New England system of railroads were completed before those of any other section. Boston was handicapped greatly in its commercial development by the fact that no large, navigable river led from it into the interior.

The Hudson is the most important, commercially, of the tributaries to the Atlantic from the United States. Because of the drowning of the Hudson Valley, deep water extends 100 miles from the mouth, and the river is navigable 50 miles farther, to Troy.

The belt of relatively weak rocks along which the Hudson Valley developed contains, farther north, Lake Champlain and the Richelieu River. This long, narrow lowland, which extends from New York City to the St. Lawrence River near Montreal, was called by the Indians "The Grand Passway." General Burgoyne (1777) and General Prevost (1814) used it to invade the United States. When the Champlain Canal was opened between the Hudson River and Lake Champlain, water transportation was available throughout its entire length. The Mohawk Valley and the low plain to which it leads furnish an easy route between the Hudson River and Lake Erie; the highest point is only 445 feet above sea-level. Its drowned-valley harbor and unparalleled connection with the interior have been leading factors in the growth of New York City.

South of the Hudson River, most of the larger rivers are navigable to the "fall line," where the streams, in passing from

the hard, crystalline rocks of the Piedmont Plateau to the weak, stratified rocks of the Coastal Plain, have developed falls and rapids. Along this line are Philadelphia, Baltimore, Richmond, Petersburg, Raleigh, Columbia, Augusta, Macon, and Columbus (Fig. 306). Ocean-going vessels ascend the Delaware River to Philadelphia, and smaller boats go up as far as Trenton. Several drowned tributaries of Chesapeake Bay have some commercial importance.

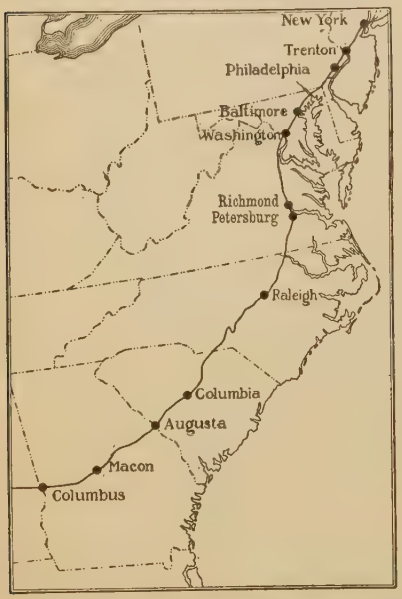

Fig. 306. Map showing leading cities along the "fall line."

The drowned streams of the Virginia region were deep enough to accomodate the light-draft boats of the colonial period, and served the settlers as roadways. The plantations were arranged in narrow belts along the stream courses. For a century, travel in tidewater Virginia was largely by water; little attention was given to road building. Ships came from England direct to the wharves of many of the plantations, to exchange for tobacco the manufactured goods needed in the colony. Under these circumstances, no important collecting and distributing centers developed. To 1700, Jamestown was the only place worthy of being called a village. Laws were passed for the care of the all-important waterways; ships on coming to anchor were not permitted to throw their ballast into the channel, and trees that toppled into the streams were to be removed promptly. In South Carolina, the streams were not drowned sufficiently to render many of the smaller ones navigable. Hence Charleston became the commercial center of the colony, and soon also the social and political center. In general, freight rates decrease as the size of the cargo increases, and accordingly the tendency has been to build larger and larger boats. As a result, many of the streams of the Coastal Plain, once important in trade, were long since abandoned by commerce.

Mississippi River System

The Mississippi river system is by far the most important in the United States (Fig. 305). The main river has more than 50 tributaries that were navigated more or less in 1907. The navigable waters of the system aggregate nearly 14,000 miles, and border or

traverse 21 states. The Mississippi River itself is navigable for large steamers and barges from its mouth to St. Louis (1,256 miles), and for smaller boats to St. Paul (729 miles farther). The Ohio River, now much the most important, commercially, in the United States, is navigable throughout its length of 967 miles. The Missouri River is navigable for small boats to Ft. Benton, in Montana, but now is used but little. Other tributaries of the Mississippi are navigable for varying distances, as shown by Fig. 305.

Influence on early development of the West. At the close of the Revolutionary War, the Mississippi River was made the western boundary of the United States, and the supposed length of the river set the initial width (north and south) of the country.

The Mississippi River was an unsatisfactory international boundary line, for (1) its position shifts (p. 368), (2) the navigation of the river by the Americans from the east side and any foreign people from the west side would have led to friction, and (3) the river basin is a natural unit. Until 1803, the ultimate ownership of the basin was in doubt. At different times the plans of Spain, France, and England looked to getting the eastern part of the basin as well as the western. To the American settlers along the Ohio River and its tributaries, the free use of the lower Mississippi as an outlet to market was of the greatest importance. Disgusted at the attitude of the government in its negotiations with Spain, which controlled the mouth of the Mississippi River and at times closed it to them, many of the western frontiersmen considered leaving the Union and attaching themselves to one of the European powers mentioned above, in order to secure the free navigation of the river. Their willingness to do this reflects not so much their lack of patriotism, as their commercial dependence upon the western rivers, and their isolation from the older section by the Appalachian Mountains. That the political unity of the Mississippi Basin was brought about by the advance of the American boundary toward the west, rather than by its retreat to the Appalachian Mountains, was due largely to the strength and sweep of the westward advance of American settlers, and to the turn of European politics.

The early western settlers could send over the difficult mountain roads to the eastern seaports only valuable articles of little bulk and weight, such as whiskey, furs, and ginseng, or live stock, which could walk to market. For years, many thousands of hogs and cattle were driven over the mountains to Charleston, Baltimore, and

Philadelphia, but salted and dried meats, flour, tobacco, and the other export products of the frontier had to go down the Mississippi River to New Orleans. Roads were few and poor, and the settler found it highly desirable to locate his farm within easy hauling distance of a navigable stream. The influence of navigable waterways upon the distribution of population is shown clearly by the census maps of 1820 (Fig. 439), and several later years.

One of the most used of the early boats on the western rivers was the *flatboat*, commonly 15 feet wide (said to be the maximum

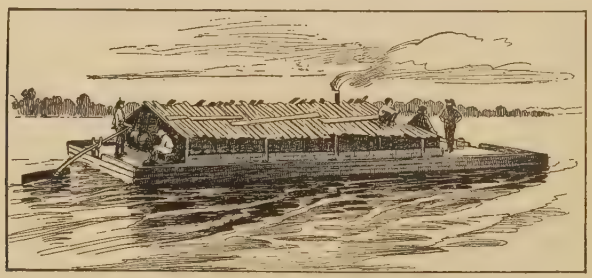

Fig. 307. A typical flatboat.

width which could pass through the rapids of the Ohio River at Louisville), and 40 to 50 feet long (Fig. 307). While these boats served for down-stream navigation, they were almost useless against the current of the Mississippi. Ordinarily they were broken up and the lumber sold at New Orleans. In these early days, freight was carried up-river largely in keel boats or barges. Most of them were equipped with oars, poles, and sails, and in many cases were dragged laboriously up-stream by men on the bank, tugging at a long rope. The average length of the trip from New Orleans to Louisville was three months, and in many cases it required four months.

Influence of steam navigation on the development of the Interior. The first steamboat appeared on the Ohio River in 1811, and by 1817 it was apparent that steamers could cope successfully with the currents of the rivers of the Interior, and that they would increase greatly the commercial value of the streams. For a time, steamboats could not be built fast enough to take care of the business. In 1820, there were 72; in 1826, 95; in 1829, more than 200; in 1830, 230; by 1843, 600; and in 1848, 1200. During these years the steam-

boats (Fig. 308) were changed greatly with a view to adapting them to the conditions of the inland waters. In 1835, the ordinary Mississippi River steamboat was about 150 feet long, 18 feet wide, and drew 6 feet when loaded. In 1855, when steamboat building had been perfected, the better boats were 225 or more feet long, about 35 feet wide, and drew when loaded 48 or 50 inches. These changes meant (1) greater capacity, (2) greater speed, (3) less steam

Fig. 308. Mississippi River steamboats at New Orleans.

in proportion to size and load, (4) less danger of grounding, (5) a great extension of the navigable waters, and (6) a great reduction in the cost of travel and transportation. By 1850, the time involved in up-stream travel had been reduced to about 1/18 of what it had been before the appearance of the steamboat. This meant, for example, that the steamboat brought New Orleans nearly as close to St. Paul, for certain purposes, as it had formerly been to Baton Rouge. The cost of travelling by water from New Orleans to Pittsburgh before the advent of the steamboat is said to have been about $160. In 1830, steamboats offered cabin passage and food for the same trip for $35 to $45. Deck passage, without food, was much cheaper. In general, the steamboat soon reduced freight charges to about 1/3 of what they had been, and finally to 1/4 and less. Because of these things, steamboat navigation became one of the greatest factors in the development of the Interior.

The population of the Interior, commercially dependent for the most part on the rivers, increased from 2½ millions in 1820 to 4⅗ millions in 1830 and 6⅓ millions in 1840. Probably no single factor contributed more than the steamboat to the rapid expansion of population during these years. Thousands settled along the tributaries of the Mississippi having steamboat service, and almost overnight river towns sprang up at favored points. The total value of the commerce of the western rivers in 1850 was estimated at $550,000,000.

The leading centers of steamboat trade. During the period of steamboat supremacy, the river commerce of the Interior gravitated largely toward four commanding centers — Pittsburgh, Cincinnati, St. Louis, and New Orleans.

For some time before the opening of the Erie Canal (1825, p. 434), Pittsburgh was the eastern gateway to the Mississippi Basin. Important roads connected it with the eastern seaboard. In 1818, the merchandise carried by wagon to Pittsburgh from the East was valued at $17,885,000. The position of the city at the junction of the Monongahela and Allegheny rivers gave it many advantages. The former brought coal from West Virginia, while the latter gave it command of the white pine of western New York. About 1833, some 33,000,000 feet of lumber descended the Allegheny River to Pittsburgh each year. The principal products of the Pittsburgh mills during these years reflect these advantages, together with the command of iron and the products of the surrounding farms. They were implements and machinery, iron ware, cabinet ware, lumber, furniture, flour, and liquors. These things were sent by river throughout the Interior.

Cincinnati had several marked advantages for the development of river trade. Situated mid-way on the Ohio and near the northernmost point of the great bend of the river, it is the nearest important river town for a large and fertile region north of the Ohio. It is also opposite the Licking Valley in Kentucky. The deep channel and favorable bank of the river along the entire city front gave it special facilities for handling steamboat traffic. It was connected (in 1832) by canal with Lake Erie (Fig. 317). By river Cincinnati received most of the implements and supplies, or the materials for their manufacture, needed by the tributary farming region. By the same means were shipped the products of her flour mills, breweries, distilleries, and slaughtering and packing

houses, which had been established to use the products of the surrounding country. (Why was it desirable to manufacture these things near the points where the grain and animals were produced?) These advantages enabled Cincinnati to become the leading city of the Ohio Valley.

For years most of the capital and business enterprise of St. Louis were engaged in the river trade, though later the city became an important manufacturing point. The following were the chief advantages which made it, next to New Orleans, the greatest steamboat center on the Mississippi system. (1) It is situated near the mouths of the Missouri, Illinois, and Ohio rivers. (2) There is a significant difference in the depth of the Mississippi River above and below St. Louis (Fig. 309). At St. Louis, therefore, cargoes were exchanged between the lighter-draft boats of the upper river and those of heavier draft operating on the lower river.

Because of its commanding position near the mouth of the Mississippi River, New Orleans had for years the greatest commerce of any city west of the Appalachian Mountains. The population of New Orleans more than doubled between 1830 and 1840, in spite of the growing sand bars at the mouths of the river, frequent inundations, and disease (p. 376). No other important American city grew so fast. But even before the Civil War, the commerce and growth of New Orleans had received several serious blows. When canals were opened between the Great Lakes and the Ohio, Wabash, and Illinois rivers (p. 436), enormous quantities of goods from Ohio, Indiana, Illinois, and even from parts of Iowa and Missouri, sought the eastern markets by way of the Great Lakes and the Erie Canal, rather than the southern markets. New Orleans particularly was injured as an importing city. It is some 1500 miles farther than New York from the industrial centers of northwestern Europe, and the connection of New York with the Interior by way of the Hudson River, Erie Canal, and Great Lakes was superior to that of New Orleans against the current of the Mississippi. The railroads continued the work of the canals, and made trade along east-west lines vastly greater than that along north-south lines.

In addition to the four cities mentioned, many smaller cities and villages depended largely on river transportation and trade. Such were Louisville, whose location was determined by the rapids of the Ohio River; Nashville and Kansas City, profiting commercially (Why?) from their respective positions on the great bends of the

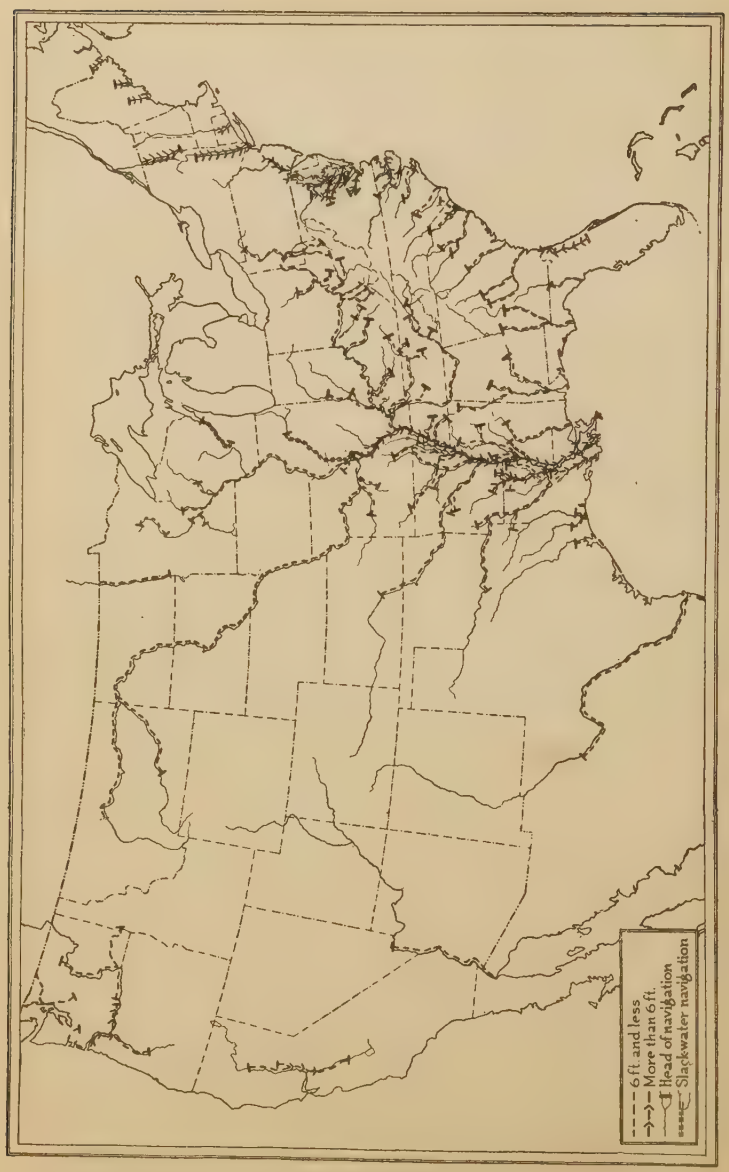

Fig. 309. Map showing the navigable depths of the rivers of the United States. (After Inland Waterways Commission.)

Cumberland and Missouri rivers; and Peoria, the leading city of the Illinois Valley.

Decline of river navigation. For years, commerce on the Mississippi River and its tributaries has been relatively insignificant in amount. The decline began at different times on different rivers — for example, in 1855 on the Illinois River, and about 1883 on the Yazoo River. The causes of the decline also differed somewhat, but the leading ones were of general application. (1) The channels of many of the rivers were shallow, crooked, and shifting. (2) The depth of water varied much from time to time, and from place to place (Fig. 309). For the latter reason alone, there could not be a unified transportation system. Boats suited best to the conditions of the Great Lakes or coastwise trade could not be used on rivers or canals affording but 6 feet of water, and boats giving the most economical service for 6 foot channels could not be used in shallower waters, and so on. This was especially serious because of the importance of through traffic in American transportation. The great size of the United States and the high degree of industrial specialization in its different parts mean that much freight must move long distances. (3) The use of the rivers forced freight in many cases to take indirect, roundabout courses. (4) The waterways in the central and northern parts of the country were closed for a part of each year (p. 380). (5) Water transportation was relatively slow. (6) In general, the methods, terminal facilities, etc., of river and canal trade have remained unimproved since the Civil War, and have been less and less able to meet the demands of modern business. (7) When railroads were built throughout the Interior, these conditions proved fatal to the river trade. The railroads at once obtained most of the passenger trade, and most of the traffic in perishable and expensive freight. The rivers could, and in the future can, hope to compete only in the transportation of heavy, bulky, and non-perishable commodities such as coal, grain, lumber, building stone, and the like. It is highly desirable that the navigation of the larger rivers be improved, so that they may assist the railroads in transporting the ever-increasing quantities of cheap freight (p. 438).

Even since the loss of most of their business, many of the waterways have been of importance in regulating railroad freight rates. Most of the river towns that obtained good railroad connections did not suffer greatly from the decline of river trade; but to river

towns without railroads the passing of the steamboat was a serious blow, and many such places decreased in population.

Present traffic. The Ohio and its tributaries now have the largest river trade in the country, and Pittsburgh is the leading inland city in the volume of its river commerce. The traffic is mainly in coal (brought from West Virginia on the Monongahela and Kanawha rivers), lumber, logs, sand, and gravel. On the upper Mississippi, the declining traffic is largely in rafted logs and lumber, and in sand. The principal commodities transported on the lower Mississippi are coal, lumber, crude petroleum (from Louisiana), and plantation products such as cotton, sugar, and rice.

In 1906, the total traffic for the entire Mississippi system, including rafts and harbor traffic, amounted to only about 30,000,000 tons. As in early days, most of the freight moves downstream.

Pacific Rivers of the United States

The rivers of the United States tributary to the Pacific Ocean have a combined navigable length of about 1,600 miles. None of them affords navigation far inland (Fig. 305), the San Joaquin and Sacramento rivers, especially, being nearly parallel with the coast. The Columbia is commercially the most important river of the Pacific coast. Ocean steamships reach Portland (some miles up the Willamette), 110 miles inland, and river boats go much farther up the Columbia and the Willamette, and navigate parts of the Snake, and other tributaries.

As the only river rising east of the Cascade-Sierra Nevada ranges and directly tributary to the Pacific Ocean, the Columbia was the key to political expansion on this portion of the coast. The fact that its divergent branches approach closely the headwaters of the Saskatchewan and Missouri rivers, along which English and American explorers and fur traders advanced, was sufficient to precipitate a dispute between Great Britain and the United States for the possession of the Oregon country.

The Colorado River is navigable for light-draft boats in its lower course (Fig. 305), but is little used commercially.

COMMERCE OF THE GREAT LAKES

General features of the lakes. The Great Lakes constitute the most important inland waterways in the world. Their shoreline in the United States is more than 2,700 miles long, if measured from headland to headland, and more than 4,300 miles, if measured

in detail. They are connected by canals with the Atlantic Ocean and the Mississippi System (Fig. 318). Unfortunately, the shores of the Great Lakes have few naturally good harbors. Several of the leading cities and many of the villages on them had their locations determined chiefly by the mouths of creeks or rivers. Thus Buffalo was located in part by the mouth of Buffalo Creek, Cleveland by the mouth of the Cuyahoga River, and Chicago by the river of the same name. The entrances to these and similar streams were shallow, and easily choked by drifting sands. As a result, harbor improvement has been a frequently recurring problem throughout the history of the cities concerned.

The Great Lakes afford conditions for transportation in many ways vastly superior to those of the rivers, and their commerce has grown rapidly in spite of railroad competition. At present, the principal commodities carried on the Lakes are iron ore, coal, lumber, and grain — raw materials of great bulk, and not requiring rapid transportation. In 1910, the total domestic shipments on the Great Lakes amounted to more than 86,000,000 net tons, of which more than half was iron ore.

Early navigation. Apart from their use by the Indians, the Great Lakes were navigated systematically first by the French fur traders from eastern Canada. They discovered Lake Huron first (1615), by way of the Ottawa River (Fig. 310), and used the lower Great Lakes last, because of the hostility of the Iroquois Indians. They navigated the Great Lakes in light canoes which could be used also on the streams leading to and from the Lakes, and could be carried over the numerous portages.

The lines which the French used in passing back and forth through the Great Lakes region were determined in several cases by the work of glacial waters (compare Fig. 310 with Fig. 298). Almost without exception, these lines have continued to be of importance in trade and travel. Canals were cut across several of the old portages (compare Figs. 310 and 317). Turnpikes and railroads followed or paralleled the old lines. A number of villages and cities grew up at strategic points where the French had built forts to guard the lines of trade. Between Presque Isle (opposite present city of Erie, Fig. 395) and the Allegheny River there ran at different times buffalo trail, Indian path, trader's trace, military road, turnpike, and railroad. A canal, soon abandoned, also once connected the city of Erie with the Ohio River. Long the favorite route of the French between the St. Lawrence River and the Great Lakes, the Ottawa Valley was followed by the Canadian Pacific Railroad westward from Montreal, and is to be followed by the projected Georgian Bay Ship Canal. In connection with the latter, much water power will be made available, and the Ottawa Valley probably will become one

of the most important industrial sections of Canada. The above facts illustrate the truth of a statement that "trade and civilization in America have followed the arteries made by geology."

The first American sailing vessel appeared on the Great Lakes in 1797, but for a time the number increased slowly. In 1812 some half-dozen small schooners carried practically all the traffic on Lake Erie, and for several years more the business of the upper lakes was limited to that of the fur-trading stations. Further development

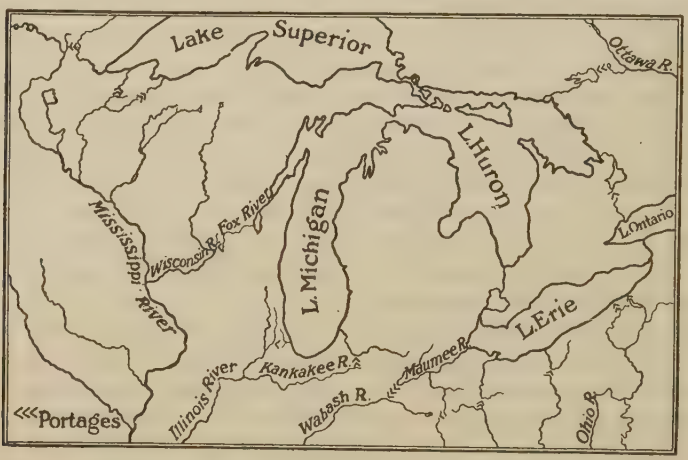

Fig. 310. Portages between the Great Lakes and the Mississippi System.

awaited the introduction of steam navigation, and the settlement of the neighboring lake and prairie plains.

Steam navigation and the settlement of the Great Lakes region. Beginning in the decade 1820–1830 there was a large movement of population from New England and New York into the Lake region. Many causes contributed to it, one of the most important being the great reduction in the expense and time involved in reaching the Interior, due to the opening of the Erie Canal in 1825 (p. 434), and the development of steam navigation on the western Lakes in the thirties. The first steamer appeared on Lake Ontario in 1816, but not till ten years later did one enter Lake Michigan, and not until 1832 did one visit Chicago. In 1833, there were 11 steamboats on the Great Lakes, and by 1848 there were 400 vessels, including 64 steamers. Cabin fares on the better boats from Buffalo to Chicago fell from

about $25 in 1838, to $6 or $8 in 1852. Steerage fare was considerably less. It was now possible, furthermore, to take household goods, farming implements, and stock into the Interior easily and cheaply.

A comparison of Figs. 311 and 312 will show how rapidly the northern parts of Ohio, Indiana, and Illinois, and the southern parts of Michigan and Wisconsin were settled between 1830 and 1850. During this period, also, Buffalo, Cleveland, Toledo, Milwaukee, and Chicago experienced their first substantial growth. They served as points of contact between the agricultural Interior and the manufacturing and commercial East. Their prosperity depended on commerce; not till later did they come to have large manufacturing interests. Between 1840 and 1860 the population of Chicago increased nearly 25 fold; the city changed from the 54th in the United States to the 8th.

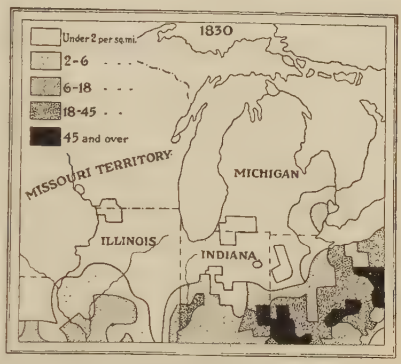

Fig. 311.

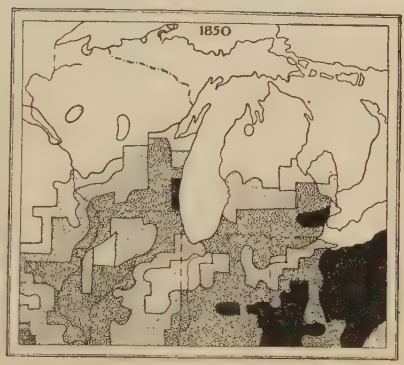

Fig. 312.

Fig. 311. Distribution of population in the Great Lakes region in 1830.

Fig. 312. Distribution of population in the Great Lakes region in 1850.

The "Soo Canal" and the opening of Lake Superior. Before the "Soo Canal" was opened in 1855 there was little commerce on Lake Superior, and for the most part its shores were an unsettled wilderness. The canal opened the borders of the lake to settlement, and permitted the systematic exploitation of their natural resources, especially the iron ore (p. 285) and lumber. The value of the canal was increased greatly in 1881, when the first enlargement was completed. Between 1880 and 1890, the population of the Lake Superior counties of Michigan, Wisconsin, and Minnesota increased

respectively 90 per cent, 400 per cent, and 800 per cent. The canal contributed greatly to this remarkable growth. In 1896, the canal was given a depth of 20 to 21 feet, and a further enlargement is now being made. There is also a Canadian canal around St. Mary's Falls.

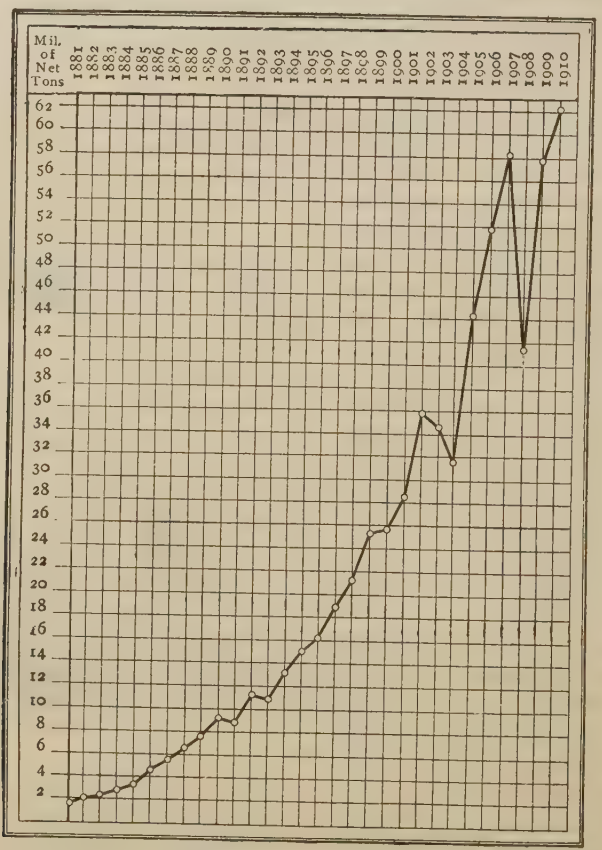

Fig. 313. Diagram showing annual tonnage passing through the "Soo Canal," 1881–1910.

In recent years about ⅔ of the total traffic of the Great Lakes has passed in or out of Lake Superior through the "Soo Canal" (Fig. 313). The tonnage passing through it during the seven months of the open season is about four times as great as that passing

through the Suez Canal during the entire year. About $^4/_5$ of the freight which passes through the "Soo Canal" is east-bound.

Traffic in iron ore and coal. Fig. 314 shows the location of the iron ore fields of the Lake Superior region. In recent years they have furnished about $^4/_5$ of the annual output of the United States. Fig. 315 shows the movement of iron ore on the Great

Fig. 314. Map showing the position of the iron-producing areas in the Lake Superior region. 1, Michipicoten district; 2, Kamanistquia and Matawin district; 3, Steep Rock Lake and Attikokan district; 4, Vermilion district; 5, Mesabi district; 6, Penokee-Gogebic district; 7, 8, and 9, Marquette, Crystal Falls, and Menominee districts.

Lakes. Most of the ore goes to Lake Erie ports, and thence by rail to the Pittsburgh region. Most of the iron ore goes to the coal, rather than the coal to the iron, because the amount of coal needed in manufacturing steel is greater than the amount of iron ore and because, where now manufactured, the steel is nearer its market than it would be if manufactured where the iron is mined. As Fig. 315 shows, much iron ore also goes to the iron and steel centers near the head of Lake Michigan, especially to South Chicago and Gary, Indiana. At these points Indiana and Illinois coal (see Fig. 153) may be obtained cheaply, and they are close to great markets.

Many boats which bring iron ore, lumber, and grain to the eastern lake ports take coal back at very low rates. This has helped to make possible the recent establishment of the iron and steel industry at the western end of Lake Superior. It also means cheap coal for domestic and general manufacturing purposes in the region

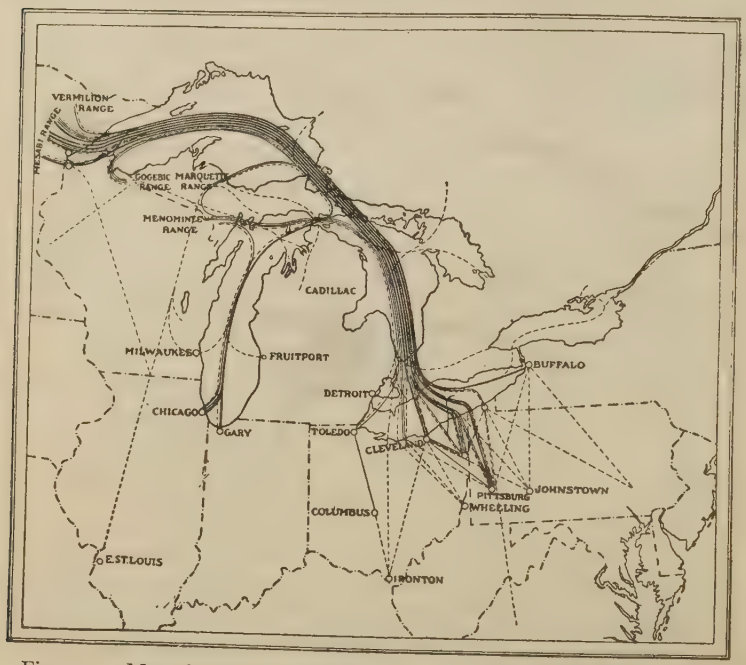

Fig. 315. Map showing movement of iron ore on the Great Lakes in 1909. (After Birkinbine.)

west of Lakes Michigan and Superior, which is without coal resources of its own.

Lumber trade of the Lakes. The western end of the great northern forest of pine, spruce, hemlock, cedar, fir, birch, etc., lies in Michigan, Wisconsin, and Minnesota (Fig. 428). Lumbering operations began in Michigan in the early thirties, and spread westward and northward. Production increased rapidly after 1850, and for many years the Lake states constituted the most important lumber district in the United States, furnishing, in 1880, ⅓ of the

total output of the country. Logs cut in the interior were floated down the streams to the lakes. At the mouths of the larger rivers busy towns developed where the logs were manufactured into lumber. First from the mill towns of eastern Michigan, and later from more distant points, the manufactured lumber was transported at low lake rates to Detroit and the cities of Lake Erie. Most of the products of the Lake Michigan mills were sent through Chicago to the prairies, the settlement of which created a demand for enormous quantities of building and fence material. With the depletion of the forests of pine near the Lakes and the larger rivers flowing into them, mill towns sprang up in the interior, from which more and more of the products have been sent to market by all-rail routes. This change and the general decline of the lumber industry in the Lake region since 1890 (p. 558), due to the cutting away of the forests, have reduced greatly the lumber trade of the Great Lakes. In 1910, 1,208,000 thousand feet of lumber were transported on the Lakes.

Movement of grain and flour. The transportation of grain and flour has been an important phase of commerce on the Great Lakes ever since the settlement of the Lake states. The movement is almost entirely from the south end of Lake Michigan and the west end of Lake Superior, to the east end of Lake Erie (Why?). The railroads are much stronger competitors for the transportation of these commodities than for that of iron and coal (Why?).

Modern lake vessels. Much of the freight on the Great Lakes is carried in steel freighters, built for speed, capacity, and strength (Fig. 316). Many are 500 to 600 feet long, and have a capacity of 10,000 to 12,000 tons. One of the largest carried 13,000 tons of soft coal in a single cargo, and on another occasion 422,000 bushels of wheat. The latter is said to have represented the production of some 30,000 acres. Another lake vessel transported more than 323,000 tons of iron ore in 27 cargoes during the season of 1907.

CANALS

General considerations. The first canal in the United States was opened in 1794, but not many of importance were constructed until the successful completion of the Erie Canal (1825) aroused great interest in canal building. The period of most active canal building extended from 1825 to 1837. Altogether, about 4,500 miles of canals have been constructed in the United States (Fig. 317). Most of them were designed to extend and supplement

natural waterways. The more important ones were of three classes: (1) Those along the Atlantic coast, connecting bays or rivers between which the natural water routes involved much greater distances. (2) Those connecting, or begun with the intention of connecting, the leading Atlantic seaports with the Ohio River or the Great Lakes. (3) Those connecting the Great Lakes with the Mississippi System. As Fig. 317 shows, many feeders were built for the main canals.

Of the 4,500 miles of canals constructed, nearly 2,500 miles, costing about $80,000,000, have been abandoned. Most of the con-

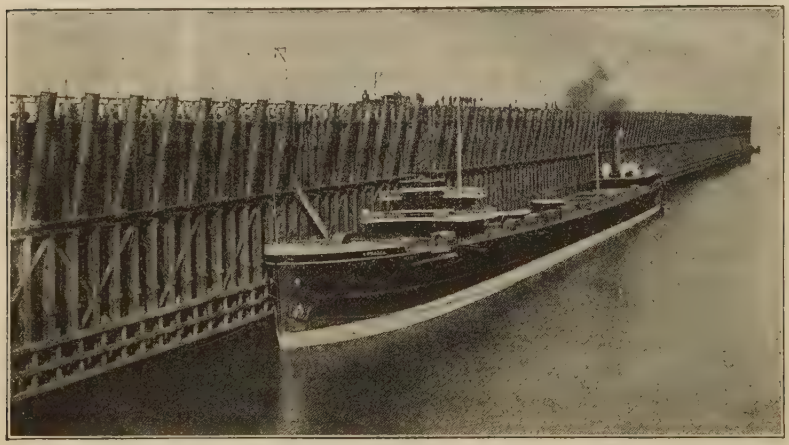

Fig. 316. The Coralia loading ore at Escanaba. (Copyright by Detroit Publishing Co.)

ditions which contributed to the decline of river navigation (p. 425) contributed with even greater force to the decline of the canals. They were all shallow, and the canal boats therefore of small capacity; many varied in size in their different parts, retarding through traffic. The canal boats depended largely on animal towage. Some of the canals were located unwisely, some were managed badly, and most of them fell an easy prey to railroad competition. Fig. 318 shows the canals used more or less in recent years, and Fig. 319 suggests the appearance of one of them.

The Erie Canal. The Erie Canal, connecting the Hudson River with Lake Erie at Buffalo (Fig. 317), was built by New York to control the trade of the central and western parts of that state, as

well as to gain the trade of the Great Lakes region, toward which settlement was setting. Much flour, meat, and other products of the former sections were going down the Delaware and Susquehanna rivers to Philadelphia and Baltimore, and some were seeking the Canadian markets along the St. Lawrence River. Such a canal was demanded also by military considerations. In the event of another war along the northern frontier, some way better than had been available in the War of 1812 was needed to get supplies to the shores of the Lakes.

Fig. 317. Map showing principal canals constructed in the United States.

The canal became a great highway of expansion into the Interior, and a great outlet for surplus western products; it caused the rapid growth of Buffalo, Rochester, and other places along its course; it increased land values throughout the region tributary to it; and it helped to transform New York City from a market town for the Hudson Valley, into the leading commercial city of the country. The cost of transportation between Albany and Buffalo fell from $88 to $5.98 a ton in the twenty-six years after the opening of the canal. The tolls collected on the canal paid for its construction in 10 years.

Until the late 1860's, the Erie Canal was the most important transportation route between the Great Lakes and the Atlantic Ocean. In 1860, 1,500,000 tons of western produce went to tidewater by way of the canal, and only 900,000 tons over the four leading trans-Appalachian railroads. In 1866, the freight carried by the canal was 60 per cent of that moved across New York. Soon

after this it began to decrease, and the tonnage on the canal has been small for years. The people of New York voted in 1903 to spend $101,000,000 in improving the canal, and this work is now in progress.

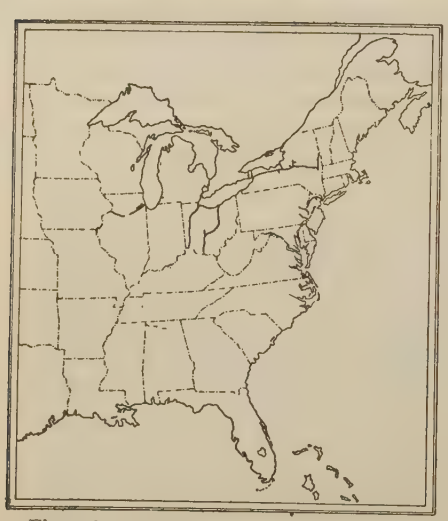

Fig. 318. Map showing canals actually used for purposes of transportation in 1906. (Data from map by U. S. Bureau of Corporations.)

Canals between Great Lakes and Mississippi System. It is impracticable to consider here, one by one the different canals which connected the Great Lakes with the Ohio and Mississippi rivers (Fig. 317). In general, they injured the cities and trade of the Mississippi River (p. 423), and benefited greatly the cities and commerce of the Great Lakes. For a time, most of them were powerful factors in the development of the sections which they traversed. In addition to bestowing special benefits in different cases, they cheapened transportation, opened new markets, raised the prices of

Fig. 319. View on Hennepin Canal, Illinois.

farm products, lowered the cost of imported merchandise, increased land values, stimulated the growth of population, and helped build up towns and cities. The last point may be illustrated in the case of Chicago and the Illinois and Michigan Canal, which connects the lower Chicago River with the Illinois River (Fig. 317). The canal made Chicago the gateway of a large and fertile region to the southwest of Lake Michigan. The imports of the city in-

Fig. 320. Map showing improved waterways of Germany and the Low Countries. (After Chisholm.)

creased from about 2½ millions in 1847 to over 8¼ millions in 1848, the first year of the canal. The exports increased from a little over 2¼ to nearly 10¾ millions in the same time. The canal helped Chicago to become, in the early fifties, the largest grain and lumber (p. 433) market in the world. The population of the city rose from 16,859 in 1847 to 60,652 in 1853. Some of these canals have been abandoned, and for years the rest have been used but little.

Foreign canals. Several foreign countries have systems of canals suited to modern conditions of transportation. This is true particularly of Germany (Fig. 320). One of the important canals of this country (the Kiel Canal) was built to permit ships to pass

between the Baltic and North seas without going around Denmark. The Manchester Ship Canal (Fig. 321) allows ocean-going ships to reach the docks of Manchester from Liverpool.

IMPROVEMENT OF AMERICAN WATERWAYS

Why waterways should be improved. It has been apparent for some years that the larger rivers of the United States should be so improved as to make possible economical transportation upon

Fig. 321. Scene on the Manchester Ship Canal.

them. This is desirable because (1) water transportation is normally cheaper than rail transportation, and if the cost of transportation is reduced, the price to the consumer of the commodities transported will tend to be lower; (2) waterways tend to keep down the rates of competing railroads; and (3) the railroads in recent prosperous years have been unable to handle promptly the traffic of the country during the busy season. The products and trade of large sections of the country are increasing much faster than the transportation facilities of the railroads. One of the leading railroad officials of the country estimates that to develop the railroads of the United States so that they can handle the traffic of the near future would require the expenditure of some $6,000,000,000. The Inland Waterways Commission estimated that to develop ade-

quately the inland waterways of the country would cost somewhere between $500,000,000 and $800,000,000.

Leading improvements needed. The leading improvements advocated by the Inland Waterways Commission are: (1) A deep canal (at least 20 feet) between the Hudson River and the Great Lakes. The new Erie Canal will have a depth of 12 feet. (2) A deep inner waterway along the Atlantic Coast from New England to Georgia (Fig. 322), following approximately the line of the old "Inland Waterway" (p. 359). (3) A deep waterway between Lake Michigan and the Gulf of Mexico. This involves the extension of the Chicago Sanitary and Ship Canal (built primarily to dispose of the sewage of Chicago) to the head of navigation on the Illinois River, and the improvement of the Illinois and Mississippi rivers. Such a waterway would be of great importance to the trade between the northern and southern parts of the Interior, and, following the opening of the Panama Canal (p. 533), to the trade of the northern Interior with the Pacific Coast, and with foreign countries both to the south and across the Pacific Ocean. (4) A canal to connect Puget Sound and the Columbia River.

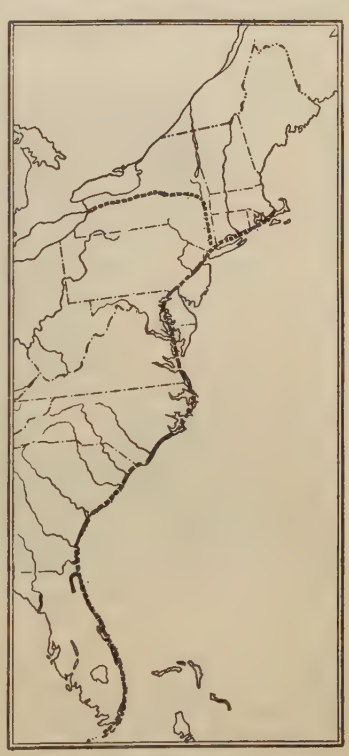

Fig. 322. Map showing course of proposed inner waterway along Atlantic Coast, and Hudson River—Erie Canal route to Great Lakes.

A canal 25 feet deep is being dug across Cape Cod (Fig. 323), which will form a link in the Atlantic coast improvement. It will shorten the water trip between New York and Boston, and will do away with the voyage among the dangerous shoals south and east of Cape Cod, where so many vessels have been wrecked.

Water Power

Use in the past in United States. Water power has located many manufacturing cities in the United States, and contributed largely to their growth. It was used first in a large way in New England, where it constitutes one of the leading natural resources. Amoskeag Falls, on the Merrimac River, made Manchester; Franklin Falls, Nashua, Lowell, and Lawrence were located by other power sites of the same river. A number of other New England rivers have similar importance, industrially. Bellows Falls, Holyoke, Berlin, Biddeford, Lewiston, Rumford Falls, Augusta, and Bath are among the busy industrial centers created largely by water power. There are many water power cities farther west. Grand Rapids, the second city of Michigan and a leading furniture manufacturing center, is an example. Located 40 miles inland at the rapids of the Grand River, its first lumber mills were at a disadvantage compared with those on the shores of the Lakes (p. 433; Why?). As a result, cabinet shops and furniture factories were soon established. (What was gained by doing this?) The power afforded by the river was soon outgrown, and the timber supply in the vicinity exhausted, but the advantages of an early start, and of established plants with world-wide reputations for furniture of superior quality, keep the city to the front. Similarly, St. Anthony's Falls and command of the forests and wheat-fields of Minnesota made Minneapolis an important manufacturing city. The settlement of the Red River Valley began in the middle seventies (p. 402), and in 1876 Congress provided for the construction of a wall behind these

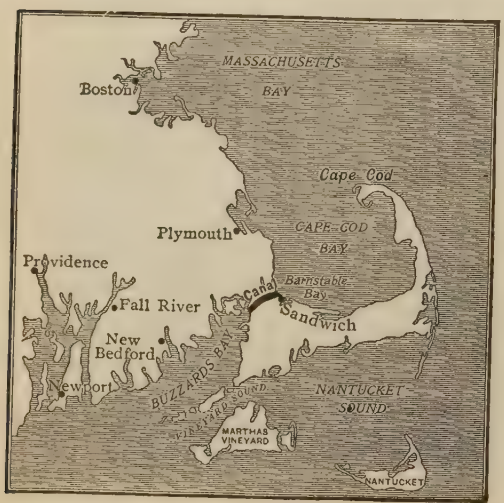

Fig. 323. Map showing canal across Cape Cod.

falls, to prevent erosion and increase the discharge of water. In 1881, the improved power operated 28 flouring mills with a yearly capacity of more than 20,000,000 bushels of wheat, representing the product of 1,250,000 acres. The falls also furnished power to 17 lumber mills. The population of Minneapolis increased from less than 47,000 in 1880 to nearly 165,000 in 1890. In 1905, the value of the flour and grist mill products of Minneapolis was about 9 per cent of the total for the United States.

Water power formerly had certain disadvantages, because the mills using it had to be located close to the source of the power. Coal was abundant and cheap, and was used more and more for manufacturing purposes. In 1870, streams furnished 70 per cent of the total power used in New England, 50 per cent of that used in the Middle Atlantic States, and 49 per cent of that in the South Atlantic States. Thirty years later, these percentages had fallen to 35, 14, and 11. Water power continued to be used most in connection with long-established industries. It also continued to be used largely in connection with certain industries presenting special conditions, such as the paper and pulp industry. Beside an abundance of clear water, this industry is favored by nearness to (1) forests affording the raw material, and (2) markets. Its leading centers are in New England, the Adirondack region of New York, and the lower Fox Valley in Wisconsin.

Present conditions and future importance. During recent years there has been a great increase in the use of water power in the United States. In 1900, 1,454,229 horse power were developed from water, and in 1908, 5,356,680 horse power. This change has been due largely to the following conditions, which also will help to bring about an increasing use of water power in the future: (1) There have been rapid developments in the transmission of energy in the form of electricity. Electric power developed by falls and rapids (*hydro-electric* power) is transmitted some 220 miles in California, 300 miles by a Colorado company, and 500 miles in Italy. On the basis of a radius of transmission of 200 miles, a water power could, if sufficient, serve an area of 125,000 square miles. In the future, few places in the United States will be beyond the reach of hydro-electric power. Power from Niagara Falls now runs street cars, lights buildings, and is furnished very cheaply for industrial purposes in Buffalo and other cities as far away as Utica. On the Canadian side, it is carried to various cities and villages as far away

as the Detroit River. Snoqualmie Falls, Washington, furnish power for electric lights, street railways, motors, etc., in Seattle and Tacoma, some 50 miles distant. (2) In some ways, electric energy is superior to other kinds for large plants, and it also has a great advantage over other forms of power in its capacity for subdivision, so that it may be carried economically to the small user. (3) In many places, hydro-electric power is even now cheaper than power obtained from coal.

About 26,000,000 horse power are developed now from coal in the United States. It is estimated that of this amount some 15,000,000 horse power could be developed by water with an average saving of $12 per annum per horse power, or a total saving of $180,000,000. In addition to the $180,000,000 gained by the substitution, there would be saved each year about 150,000,000 tons of coal. This is about one-third the coal mined in the United States, so that the substitution would lengthen greatly the duration of the coal supply (p. 281).

As the supply of coal diminishes and its cost increases, electricity developed by water will be used more and more for transportation, lighting purposes, and manufacturing. Certain railroads already have acquired water power sites in the western mountains, with a view to moving their trains over the mountains by hydro-electric power. Doubtless the time is not distant when most railroads, street cars, and inter-urban lines will be operated in this way. Ultimately, nearly all manufacturing industries will depend largely on water power, and it is fortunate indeed for the future of the United States that no other nation has more available water power.

Amount and distribution of water power in the United States. In view of the part which water power is to play in the life of the nation, its amount and distribution are matters of great interest and importance. The total amount has been estimated on several bases. (1) If the amount of water available in the streams during the two weeks of lowest water were used throughout the year, and all above that amount escaped unused, about 37,000,000 horse power could be developed. This is called the *primary* horse power. (2) If plants were established to develop the minimum power available for the six high-water months, there would be about 66,500,000 horse power per year. (3) If the flood waters were stored in reservoirs, so that the streams were utilized fully, there could be developed between 100,000,000 and 200,000,000 horse power. The significance of these figures is realized best when it is remembered that now about 26,000,000 horse power are developed from coal, and only

about 5,500,000 from water. The estimated distribution of water power throughout the country on the first two bases given above is shown in the accompanying table.

TABLE SHOWING ESTIMATE OF STREAM FLOW AND WATER POWER IN THE UNITED STATES

Principal Drainages	Drainage Area. Sq. Mi.	Flow Per Annum. Billion Cu. Ft.	Horse Power Available	
			Primary or Minimum	Minimum of the Six Highest Months
Northern Atlantic to Cape Henry, Va.	159,879	8,942	1,702,000	3,186,600
Southern Atlantic to Cape Sable, Fla.	123,920	5,560	1,253,000	1,957,800
Eastern Gulf of Mexico to Mississippi River	142,220	6,867	559,000	963,000
Western Gulf of Mexico west of Vermilion River	433,700	2,232	433,760	822,650
Mississippi River, main stream	1,238,800	21,940	147,000	335,000
Mississippi River tributaries from east	333,600	12,360	2,472,590	4,940,300
Mississippi River tributaries from west, including Vermilion River	905,200	9,580	3,948,970	7,085,000
St. Lawrence River to Canadian Line	299,720	8,583	6,682,480	8,090,060
Colorado River, above Yuma, Ariz.	225,000	521	2,918,500	5,546,000
Southern Pacific to Point Bonita, Cal.	70,700	2,193	3,215,400	7,808,300
Northern Pacific	290,400	15,220	12,979,700	24,701,000
Great Basin	223,000		518,000	801,000
Hudson Bay	62,150	614	75,800	212,600
Total	4,508,289	94,612	36,906,200	66,449,310

Control of water power in the United States. In the future the control of the water powers of the United States will also mean, to a large extent, the control of the industries of the country. It is clearly desirable that the water powers be developed under conditions that will protect the public from monopoly and extortion, and that will, at the same time, afford a full, reasonable return on the capital invested in developing them. All navigable streams are under the control of Congress, both as regards navigation and their

use for power purposes. Non-navigable streams belong to the states. In the past, many valuable water power privileges have been granted to companies forever, without adequate return to the public (the original owner) or provision for its protection. It seems likely that hereafter, in most cases, ownership will remain with the nation or state, as the case may be, and that leases for definite periods will be granted to hydro-electric companies, permitting water power to be developed under conditions safeguarding the interests of the public. Many power sites in the Public Domain have been withdrawn from private entry, to await action by Congress concerning their use or disposal. More than 1,500,000 acres in 12 states, now (June, 1911) stand withdrawn.

Improving water powers. It is highly desirable that power streams should maintain a relatively even flow. If a stream can develop 5,000 horse power during brief flood stages, and only 500 horse power the rest of the time, not much more than the latter amount can be used, and the rest is lost. Protective forests about the headwaters of mountain streams and systems of reservoirs to hold storm-waters are therefore important to manufacturing interests, as well as to navigation and farming (pp. 267–269, 342).

Water power in other countries. Water power is afforded by most large streams in mountainous regions, and by many youthful streams in non-mountainous regions, especially those that have been glaciated recently. In Europe, Switzerland is likely to be the first country to utilize fully its water power resources (p. 383). The streams of Scandinavia, Austria-Hungary, France, Italy, and Germany also afford much power. Enormous power could be developed from the streams of the Caucasus and Himalaya mountains, but this is not likely to be done in the near future. Considerable power may be obtained from the streams of eastern Australia. Canada has an abundance of water power, both in the western mountains and in the eastern part of the country. In the latter section, it is due largely to glaciation. Many other countries have more or less water power, much of which will be of value to man sometime, if not so now.

Switzerland, Italy, the province of Ontario in Canada, and the provinces of New South Wales and Victoria in Australia are among the countries that have made much greater progress than the United States toward solving the difficult problems of the control of water power.

Irrigation

Irrigation means the artificial application of water to land for the benefit of plants. It is practiced in many dry regions because otherwise crops cannot be grown, and it is being introduced more and more into humid regions, in order to increase the yield of crops. Even in eastern United States, there is scarcely a year when some crops do not suffer from lack of rain, and there are occasional years of serious droughts.

The familiar statement that agriculture without irrigation cannot be carried on successfully where the annual rainfall is less than twenty inches is very misleading. The development of "dry farming" (p. 498) and the introduction of drought-resisting plants (p. 276) are changing some semi-arid regions into fairly productive farm lands, without irrigation. Again, much depends on the distribution of the rainfall. If it came just when the plants needed it, ten or twelve inches would suffice to grow many staple crops by ordinary methods of farming. The yields that would be obtained under such conditions could be increased greatly, however, by irrigation.

Practiced since ancient times. Irrigation was practiced in Egypt 2,000 years before Christ, and probably much earlier. Formerly, the extent of the irrigable area was determined directly by the height to which the Nile rose. The great Assuan dam, at the first cataract of the Nile, now controls the river, and increases greatly the area which may be watered. About 6,000,000 acres have been irrigated in Egypt in recent years.

The ancient civilizations which existed in Mesopotamia were made possible by extensive systems of irrigation. The ditches of the region have long been unused, and much land which once was cultivated is now waste. The English government has extended irrigation in India until about 50,000,000 acres are so watered (Fig. 324), an area larger than that irrigated in any other country.

Irrigation in Western United States

Irrigation was practiced first in the United States in Arizona and New Mexico. In the latter, there are ditches said to have been used continuously for 300 years by people of mixed Spanish and Indian descent. The Mormons were the first Americans (except Indians) to irrigate systematically. The conditions for irrigation were ideal on the slopes of alluvium at the base of

the Wasatch Mountains, and without irrigation they could not have been cultivated. Irrigation by Americans in the Salt River

Fig. 324. Map showing principal irrigation systems of India.

Valley of Arizona began in 1867, and in southern California a few years later.

Value of irrigated land. Irrigation transforms unproductive, worthless, or nearly worthless, land, into land producing more than

Fig. 325. The Yakima desert before irrigation. Near North Yakima, Washington. (U. S. Reclamation Service.)

Fig. 326. The region shown in Fig. 325, after irrigation. (U. S. Reclamation Service.)

the average farm land in eastern United States. (Compare Figs. 325, 326, and 327.) Irrigated lands are worth from $100 or $150 an acre for general farming purposes to $2,000 or more an acre for choice fruit lands with good orchards. In general, the great value of much of the irrigated land is due to the following: (1) The soil of arid regions is likely to be rich in mineral plant foods, because for ages ground-waters have come to the surface through capillary

Fig. 327. A vineyard near North Yakima, Washington. (U. S. Reclamation Service.)

action, and as they evaporated into the dry air they have deposited in the soil the mineral matter dissolved during their journey under ground (p. 332). In some cases when irrigating waters have been turned on the land it has been found that certain materials (alkaline salts) had accumulated in this way to such an extent that plants would not thrive until the soil was partially leached out. (2) Irrigated soils, when used rightly, are durable. Soil wash can be avoided largely, and there is a large store of soluble mineral matter in the sub-soil. (3) Irrigating waters contain fertilizing matter in solution, which is immediately available to the roots of the plants. (4) Irrigated crops, if properly cared for, get just the amount of water needed at just the time they need it. (5) In the warmer sections of the West, several crops a year may be grown. In the Imperial Valley, for example, six crops of alfalfa can be grown each year.

Area of irrigable land. As the demand for land increases with the population, it will be advisable to extend irrigation to the utmost limit. The question as to how much land can be irrigated is therefore a vital one. In 1890, irrigation experts estimated that some 100,000,000 acres in the arid West might be reclaimed in this way. Later, the estimates were reduced to 60,000,000 acres, and now only about 45,000,000 acres (an area the size of Missouri) are thought to be irrigable. In other words, the Government Reclamation Service expects that only about 5 per cent of the entire arid region can be won to agriculture in this way. The chief factors which will control the area are matters of topography and rainfall. (1) The water supply comes largely from rain and snow falling on the mountains, and the mountain catchment areas are comparatively small. Furthermore, only a small fraction of the rainfall of the arid region can be made available for irrigation (Why?). (2) The volume of many of the western rivers varies greatly (Why? Fig. 328), and in many cases it is necessary to build dams to hold the flood waters in reservoirs, so that they may be let out as needed during the growing season. Most of the larger government dams are built in narrow places in canyons (Fig. 334). Unfortunately, there are comparatively few places suited for storage of large amounts of water, and in some cases where there are good sites for dams, the tributary catchment areas furnish little water. (3) In many places the ground is too rough to make the distribution of water on it practicable. (4) In many localities the possible crops

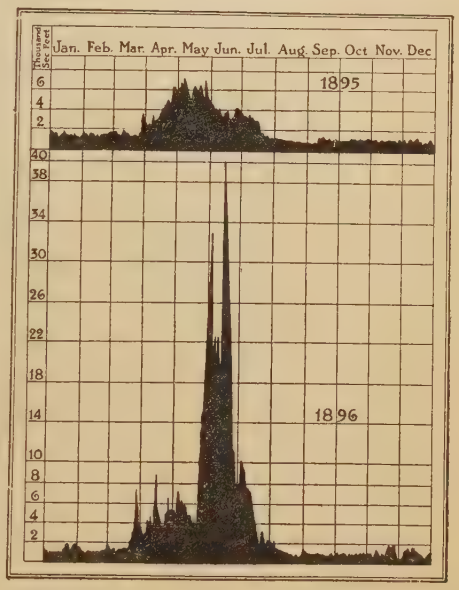

Fig. 328. Diagram showing discharge of the Boise River above Boise, Idaho, in 1895 and 1896. (Newell, U. S. Geol. Surv.)

probably would not justify the necessary expense of getting the water on the land. (5) The area which can be irrigated depends in part upon the amount of water per acre required for crops. In the case of the government projects (p. 452), this varies from 1½ to 5½ acre-feet per year. (Apart from the fact that some crops require more water than others, why should the variation be so great? Why has it been necessary to provide nearly four times as much water per acre on the Yuma Project [Fig. 331] as on the Milk River Project?)

Fig. 329. A canal lined with cement. Truckee-Carson Project, Nevada. (U. S. Reclamation Service.)

There are several reasons for hoping that the irrigable areas may prove larger than indicated above. (1) Many fields are now poorly prepared for the water, so that it spreads unevenly, and more is required than would be if the land were less uneven. With the land better prepared, the water could be spread over a larger area. (2) Much more land could be watered if loss by seepage from the canals were not so great. This now amounts, on the average, to about 25 per cent of the water, and, as the value of the latter increases, the loss probably will be reduced more and more by lining the canals with cement (Fig. 329). (3) The loss of water by evaporation from the canals also will be reduced. (In what ways does the planting of trees along the banks [Fig. 330] help to do this? In what parts of the West would this be most helpful?) (4) Many irrigators now use much more water than is necessary to secure the largest returns. This will be corrected by legislation, and by increasing intelligence on the part of the farmers. (5) Measurements to determine the amount of available water have been made on only a part of the western streams, and on most of these the readings cover only a few years.

Further work along this line may indicate that the streams can furnish more water than is now supposed. (6) Detailed topographic surveys have not been made for much of the West, and they may add new possibilities.

Government projects. Irrigation was begun in the West by individual settlers, who took up homesteads and led water to their fields from small rivers and creeks. In 1877 Congress sought to stimulate individual endeavor by legislation, but co-operation was necessary before extensive areas could be watered. This has been brought about in various ways. Many so-called "irrigation districts" have been organized to reclaim land under state laws. Since 1894, much land has been reclaimed, especially in Idaho and Wyoming, under the Carey Act, which provides for irrigation through co-operation by the nation, state, corporations, and settlers. While much was being accomplished in these ways, it became evident that the federal government must itself undertake those projects that were too expensive, too large, or too slow in producing returns, to tempt individuals or corporations. Hence Congress passed the National Reclamation Act in 1902. This act provides that money derived from the sale of public lands in the arid states shall constitute a reclamation fund. The cost of any given project is assessed against the land benefited, and is paid by the settlers in ten annual payments. The moneys returned to the government, together with the proceeds of the sale of other lands, are used again for further reclamation.

Fig. 330. An irrigating canal in the Salt River Valley, Arizona.

There are some thirty government projects under way (Fig. 331),

which, when finished, will irrigate more than 3,000,000 acres. The average cost to the settler probably will be $40.00 to $50.00 per irrigated acre. The successful prosecution of these great projects by the government has greatly stimulated private enterprise. It is impracticable to describe the several government projects

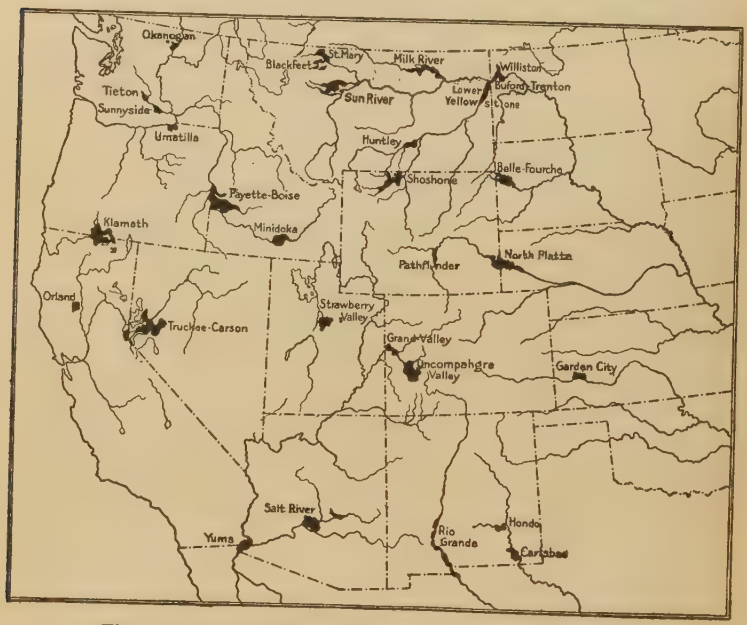

Fig. 331. Map showing Government irrigation projects.

here, but a few facts concerning some of them will illustrate the scope of the work. The Salt River Project (Arizona) has the recently completed Roosevelt dam, 280 feet high (Fig. 332). This dam forms a lake covering 16,320 acres. The water power developed by the issuing water is used to pump ground-water to irrigate more land, for lighting purposes, and in other ways. The storage dam for the Rio Grande Project is one of the largest in the world. It will make a lake 40 miles long, covering 40,000 acres, and containing 2,600,000 acre-feet of water, or nearly two and one-half times the amount in the reservoir produced by the great Assuan dam on the Nile River. The water for the Truckee-Carson Project (Nevada)

is stored in Lake Tahoe, a glacial lake in the Sierra Nevada Mountains. From Truckee River, the outlet of the lake, it is diverted into a canal and carried across to the Carson Valley to reclaim land which, in its natural condition (Fig. 333), was composed largely of sand dunes and alkali flats. Nearly half the area of the Klamath

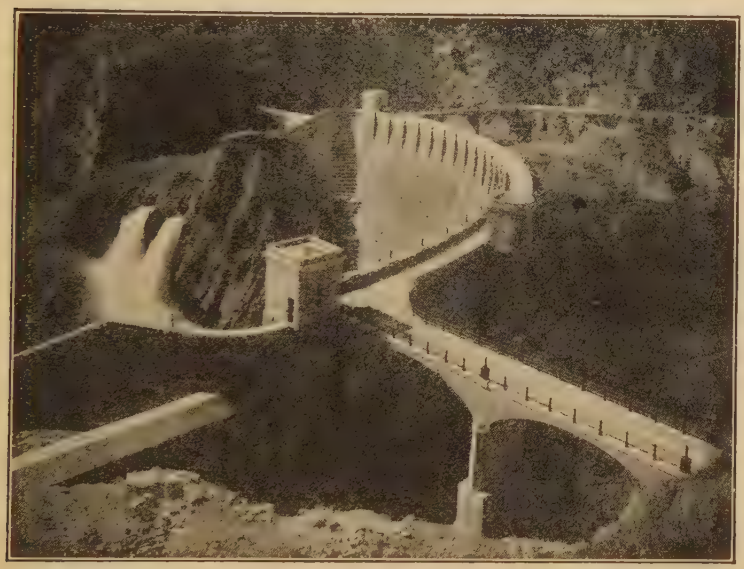

Fig. 332. Roosevelt dam, Salt River Irrigation Project, Arizona. 280 feet high; 235 feet long on bottom; 1080 feet long on top. Capacity of reservoir, 1,284,000 acre-feet. (U. S. Reclamation Service.)

Project (California–Oregon) is occupied by swamps and lakes, so that it must be drained before it can be irrigated. The water supply for the Shoshone Project, in northern Wyoming, is derived from the Shoshone River. To regulate the discharge of this river, the government has built a dam 328½ feet in height (Fig. 334), the highest structure of the kind ever built.

Crops of the irrigated lands. The soils of the irrigated lands range from heavy clay to light sand. In altitude, they occur from below sea-level up to elevations of 6,000 and more feet, and in latitude, from the Mexican to the Canadian boundary. Winter temperatures fall far below 0° F. in some of the regions concerned, and

the summer temperature reaches 120° F. in the region of the Salt River Project. In response to these and other variations, many

Fig. 333. Land in the Truckee-Carson Project before irrigation.

different crops are grown on the irrigated lands. Alfalfa and sugar beets are produced in many places. Hay, grain, and vegetables are staple products in Montana and Wyoming. In addition to these things, fruits are grown extensively in Idaho, Washington, Oregon, and Colorado. The great citrus fruit region is in southern California, and the business has grown rapidly, especially since the middle nineties. In the season of 1894–5, 5,575 carloads of oranges and lemons were shipped from the state. In ten years this increased to 31,422 carloads, or more than 10,000,000 boxes, valued in California at about

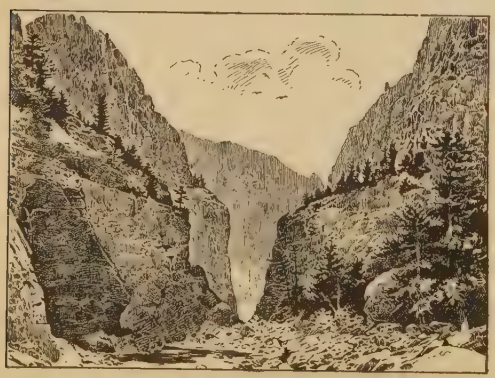

Fig. 334. Site of the great dam on the Shoshone River.

$27,000,000. In 1909-10, more than 16,000,000 boxes were shipped. The growing of deciduous fruits (peaches, pears, and the like) also has become of great importance in California, as in various other sections of the West. The shipping of these fruits in large quantities to distant markets has been made possible by the development of the refrigerator car, in which more than 90 per cent of the shipments from California are made. In the extreme southwest, the leading products are semi-tropical fruits, cereals, and alfalfa.

Population capacity of the irrigated lands. The high value of the irrigated lands encourages methods of tillage which secure maximum yields from minimum areas, and, together with the difficulty of hiring effective labor in the West, leads to small farms. In orchard regions, 5 to 10 acre holdings are common. The farm unit on the government projects is fixed by the Secretary of the Interior, and is based upon the amount of land needed to support, in comfort, an average family. On a number of the projects, the unit has been fixed at forty acres. These things mean a dense rural population. The Chief of the Reclamation Service believes that the ultimate population of the irrigated lands probably will not be far from one person to an acre.

Farm villages. In many ways, social conditions promise to be nearly ideal in most of the irrigated districts. The small farm units will make it possible for many of the farmers to live in town, going to and from their land daily. It seems probable that each 5,000 or 6,000 acres of cultivated land will support a farm village, where the farmers will have the advantage of graded schools, public libraries, etc. On a number of the government projects, the Reclamation Service has laid out town sites about six miles apart (Fig. 335), and set aside lots for churches, schools, and cemeteries. The town lots are sold to the highest bidders, the proceeds going to the Reclamation Fund. Irrigation promises to create many small villages, rather than a few large cities.

Irrigation and the National Forests. It is highly important from the standpoint of irrigation, as of navigation and water power, that the flow of the streams be uniform. The preservation of forests about the headwaters of the streams helps to bring about a more even flow of water, and partly for this reason the National Forests have been established (Fig. 336). Outside Alaska, these forest reserves have an area (August, 1911) of 144,000,000 acres. They

are cared for according to the principles of scientific forestry by the Forestry Bureau of the Department of Agriculture.

IRRIGATION IN THE HUMID STATES

Future importance. It has been estimated that the yield of every important crop of eastern United States could be doubled by irrigation. It is therefore certain to be practiced more and more

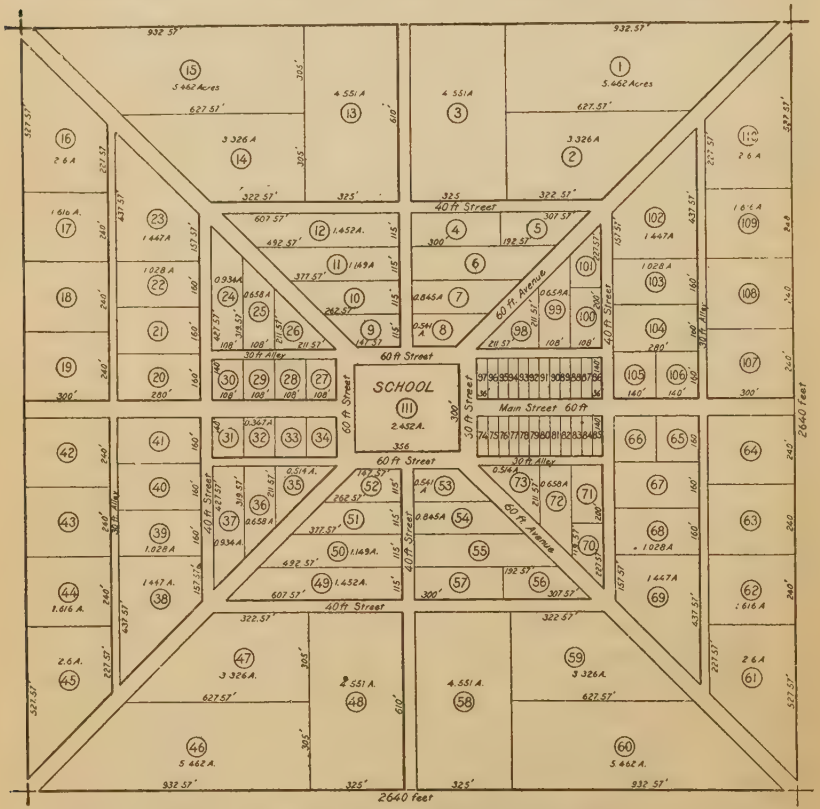

Fig. 335. Plan for village on Government irrigation project. (U. S. Reclamation Service.)

in the future, as the population increases and the demand for food grows. As in the West, the irrigator can apply just the amount of water needed at just the time required, and he can grow many more

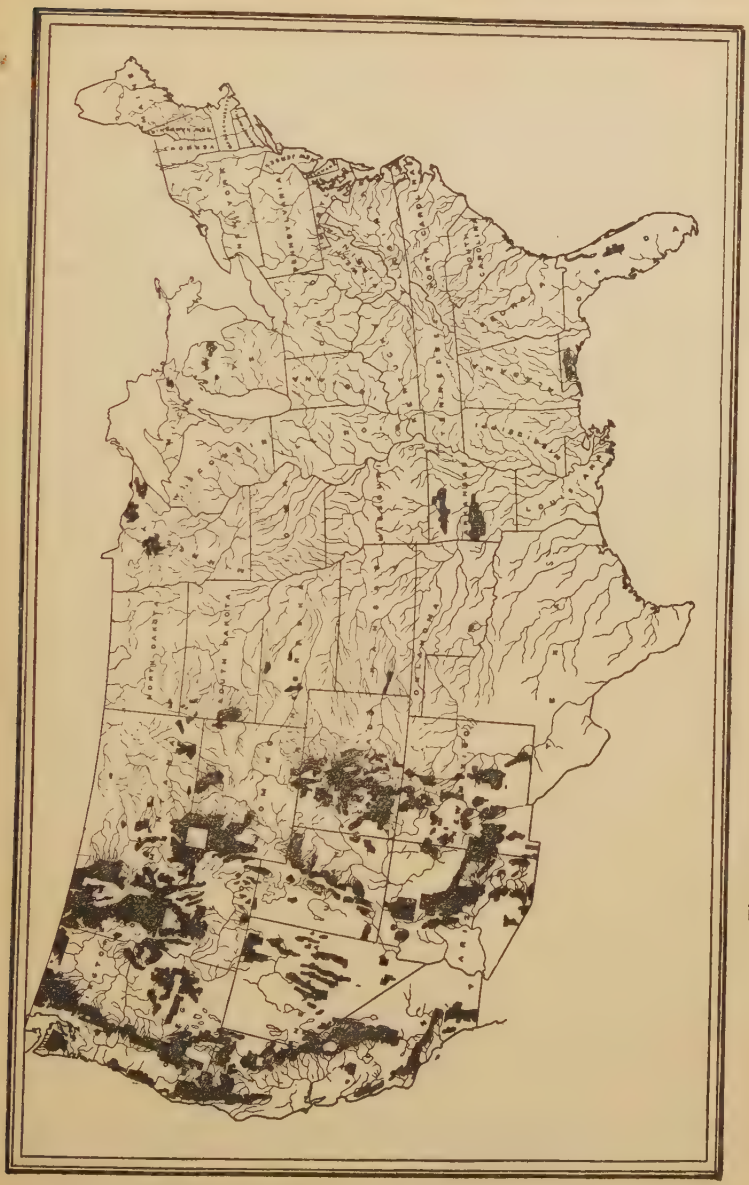

Fig. 336. Map showing distribution of the National Forests (1910).

plants on an acre than otherwise. (What would limit the closeness of stand, under irrigation?)

Present situation. Irrigation is practiced in some of the humid states in growing certain crops. For example, water is pumped from wells on to the land at various points on the coastal plain between New Jersey and Florida, to irrigate truck farms. In the latter state, irrigation has been undertaken recently on a rather large scale. This is particularly interesting, since all parts of Florida receive more than 50 inches of rain a year, and some parts more than 60 inches. But much of the soil does not retain moisture well, evaporation is great, and the fruit groves and truck farms are benefited by watering during the drier season. Their products are so valuable that even a partial crop failure means heavy losses. Recent progress in irrigation in Florida dates from the two great frosts of the winter of 1894–95, when many orange groves were destroyed. Some of the fruit growers then engaged in truck farming by irrigation, and met with such success that the practice has spread rapidly. Much of the land in Florida has to be drained before it can be irrigated, for half the state is swamp land. Irrigation is practiced extensively on the rice-fields of Louisiana, Texas, and the Carolinas.

As yet, irrigation in the East is restricted largely to special crops which warrant relatively large expenditures, such as strawberries, raspberries, blackberries and other fruits, and certain vegetables. With these crops, a small or imperfect yield because of drought is disastrous.

Reclamation of Swamp and Overflowed Lands

Wet lands of the United States

The reclamation of swamp and lake areas has been referred to incidentally in other connections (pp. 272–273, 372, 375, 400). The matter is summarized briefly here.

Area, distribution, and ownership. The Department of Agriculture estimates that the total area of swamp land in the United States is about 79,000,000 acres. It is estimated also by some that about 77,000,000 acres can be reclaimed ultimately. Swamp lands occur in many states, but the largest areas are in the states containing (1) the Atlantic and Gulf coastal plains, (2) the flood-plains of the Mississippi River and its larger tributaries, and (3) the area covered by the last ice-sheet. Among the states having

large areas of swamp land are Florida, with 18,560,000 acres; Louisiana, with 9,600,000; Mississippi, with 6,173,000; and Arkansas, with 5,760,000.

In 1849 and 1850 the federal government granted nearly all the public swamp lands to the states. More than 9/10 of these lands are now in private hands.

Status and cost of reclamation. It is estimated that nearly 16,000,000 acres have been drained, mostly in the northern interior states. In most other parts of the United States, the problem of draining wet lands received little attention until the last few years. This was due to the abundance, till recently, of good land not requiring drainage. Progress is now being made in Florida (p. 458), Louisiana (p. 273), and other states.

The cost of reclamation varies with the character of the swamp, the methods employed, and the machinery used, from $3 or so an acre, to $30 or more. In some cases ditches only are needed, and the cost is then slight; in other cases tile-draining is necessary, and then the cost depends largely on the character of the land. Along many rivers and coasts it is necessary to build dikes. The water of the swamps is then brought to certain points by drains or ditches, and pumped out over the dikes. In many such cases, rather large areas are treated as units, and improvements in methods and machinery have reduced the cost one-half in the last 15 years. The estimated cost of reclaiming 91,000 acres of Wabash River bottom lands is $8.00 an acre. In southeastern Missouri 500,000 acres can be reclaimed for about $10.00 an acre. The average cost per acre of draining the wet lands is much less than that of irrigating the dry lands (p. 452).

Results of reclamation. (1) The soils of most reclaimed swamp lands are clayey (Why?). In many cases they are "sour" and "cold" at first, but lose these characteristics under proper tillage. As a class, they are very fertile (Why?). Since most swamp areas are of little use, it is clear that drainage greatly increases land values.

The value of drained farming land varies from $20 or less an acre, to $500 and more. It depends largely on the character of the soil, the climate, transportation facilities, nearness to or distance from good markets, etc. It has been estimated that the 77,000,000 acres of swamp lands in the United States which probably can be reclaimed will have an average value of $60.00 an acre — a total value of $4,620,000,000. Their present value has been estimated at $8.00 an acre, and the average cost of draining at $15.00 an acre (perhaps too low) — making

a total of $1,771,000,000. According to this estimate, the increase in land values through drainage therefore would be $2,849,000,000. Obviously, these figures have no exact value, and serve only to give a general impression of the enormous future value of the wet lands.

(2) The products of the drained lands will increase greatly the crops of the country, and will feed and support millions of people.

Perhaps 50,000,000 acres of the present swamp lands will support a family to each ten acres, under the conditions likely to prevail in the United States a century or two hence. This would mean 5,000,000 families, and, assuming 5 persons to a family, 25,000,000 people. If the remaining 27,000,000 acres were to average one family to 50 acres, they would support 540,000 families, or 2,700,000 people. This added to the 25,000,000, would give 27,700,000. It is assumed in most estimates that the urban population dependent indirectly on the lands in question will equal the rural population. On this assumption, the total population of the present swamp regions would become 55,400,000. Probably this is putting the urban population too high. If it be taken at ¾ the rural population, the total would be 48,475,000. These considerations serve at least to show the truth of an earlier statement (p. 372) to the effect that the wet lands constitute one of the greater natural resources of the nation.

(3) An immediate effect of the systematic draining of the swamp lands will be to increase the healthfulness of the areas concerned. The principal breeding places of malaria-carrying mosquitoes will be destroyed, and that disease practically stamped out. The present annual loss to the country from malaria, due to the reduced efficiency of the sufferers, the losses to business in areas affected, etc., has been estimated at $100,000,000.

Men competent to judge have declared that the economic development of much of New Jersey has been retarded by the mosquito plague. Many places in the state have been prevented in this way from becoming residence suburbs, manufacturing centers, or summer resorts. In some localities in the southern part of the state, repeated attempts have been made to carry on the dairy industry for the nearby city markets, but in most of these cases the attacks of swarms of mosquitoes have so reduced the yield of milk that the business was abandoned. A few years ago the Legislature of New Jersey appropriated $350,000 for ditching and filling coastal marshes. The mosquito has been exterminated largely in the areas where the work has been done, and the state probably will be freed from the pest within a few years.

Reclamation of lake-covered lands. Lakes merge into swamps, and many so-called lakes doubtless are included in the estimate of swamp areas already given. Ultimately, most shallow ponds and lakes will be drained. It will always be impracticable to drain some lakes, and many others will be carefully protected and preserved (p. 403).

WET LANDS OF OTHER COUNTRIES

Large areas of wet land have been reclaimed in Europe. Much land now farmed in Holland was won from the sea. About ⅓ of England was marsh or bog land in the reign of Alfred the Great (871–901). Probably "not far from 1/20 of the tillable land in Europe was inundated and unfit for agriculture in the eighth century of our era."

Vast areas of swamp land in various tropical countries probably will remain in their present condition for a long time.

Water Supply

Apart from its support of plant and animal life, the most important use of water is for domestic and municipal purposes — for drinking, bathing, and various household purposes, for sprinkling streets, flushing sewers, for fire protection, manufacturing, and the like. It is estimated that between 50 and 150 gallons of water per person are used daily in the cities of the United States. Of this, about half a gallon per person is used for drinking.

Sources of water supply. (1) Rain-water, stored in cisterns and "tanks," is used extensively for drinking in the arid states, and for other purposes throughout the country in rural communities and villages. (2) Most of the rural population of the United States obtains water for domestic purposes from underground, through ordinary wells and springs; but no large city could get sufficient water in this way. Thousands of wells and springs have failed in recent years because the water table (p. 321) has been lowered by unwise farming and deforestation (p. 325). (3) In the Atlantic Coastal Plain, the Great Plains, and some other parts of the country where the arrangement and position of the rock strata are favorable, artesian wells (p. 326) supply large amounts of water.

Sand and gravel are in general good water bearers, while clay yields relatively little water (Why?). Many wells sunk in the glacial clays of northern United States obtain their water chiefly from associated beds or pockets of sand and gravel. Among the solid rocks, sandstone is a good water carrier, because it is porous, and shale a poor one, because it is compact. Most of the igneous and metamorphic rocks are dense, and hold little water, the largest supplies being found in cracks and other openings in the rocks.

(4) Thousands of lakes, particularly in the glaciated parts of the country, may serve as sources of water supply for neighboring cities and villages, and many are so used now. From the Great Lakes or

their connecting rivers, Buffalo, Cleveland, Detroit, Milwaukee, Chicago, Duluth, and many smaller cities obtain their supply of water. (5) Many villages and cities draw their water supply from streams. Thus New York City obtains its supply from streams and reservoirs in the Catskill Mountains and the uplands east of the lower Hudson River; Philadelphia depends on the Delaware and Schuylkill rivers, Cincinnati on the Ohio, Minneapolis and St. Louis on the Mississippi, and Omaha and Kansas City on the Missouri.

In recent years various cities have outgrown their supplies of water and have had to seek new supplies, in some cases at considerable distances and at great expense. Los Angeles is expending more than $25,000,000 in this way. Water is to be brought from Owens River, across the Mojave Desert and through the San Bernardino Mountains, in an aqueduct of steel and concrete some 240 miles long. Great reservoirs are being built, one of the dams of which is 140 feet high. The daily capacity of the system will be about 258,000,000 gallons. New York City is expending nearly $100,000,000 to obtain an additional supply of 500,000,000 gallons a day from the Catskill Mountains, more than 80 miles away.

Quality of waters. Drinking water should be reasonably clear, tasteless, and free from germs of disease. Some cities have expended large sums to guard the purity of their water supplies. Some of them have bought large tracts of land, with their lakes, springs, and other stream sources. The waters of these tracts are then protected carefully from contamination, and carried to cities in ways that prevent pollution on the way. Other cities have established filtering plants through which all the city water passes before use. Nevertheless, the use of impure drinking water is still a leading cause of disease in the United States. Many wells receive drainage from barnyards and cesspools (p. 324), many springs used as a source of drinking water are exposed to surface wash and to pollution by stock, and many villages and cities use river and lake water contaminated by sewage.

In the interest of public health many cities have discouraged or forbidden the use of private wells, and some states have laws designed to prevent the pollution of lakes and rivers. Chicago formerly discharged its sewage into Lake Michigan, from which, at some distance from shore, the city obtains its water. Because of danger that sewage would pollute the water supply, the city built the Chicago Sanitary and Ship Canal, opened in 1900 at a cost of about $50,000,000, through which the sewage is turned into the Illinois River. The sewage of Buffalo goes into the Niagara River, the water of which is used for drinking and other purposes by several towns, including Niagara Falls. Largely as a result, the typhoid death rate is very high at these places. The city of Niagara Falls is "one of the worst

plague-spots, if not the very worst, in respect of typhoid fever in the United States to-day." Surely, sewage should be disposed of in some better way than by putting it into drinking water. It can be used to great advantage, for example, on the land, for fertilizing purposes (p. 271). This is now done by some cities, especially in Europe.

For many industrial purposes, the value of water depends on the kind and amount of mineral matter it contains. Distilleries and breweries require water of exceptional purity. Laundries and textile mills need water which is clear, free from iron, and contains relatively little other mineral matter. Railroad companies spend large sums in treating the waters used in their engines, so as to make them less injurious to the boilers. Knowledge of the quality of the waters of the country is so important from various standpoints that extensive investigations of surface and ground waters are being made by the United States Geological Survey, and by various state and private agencies.

Questions

1. Are cities more likely to develop on the *inside* or *outside* of great bends on navigable rivers? Give examples and reasons.

2. Why does the cost per ton for transportation by water tend to decrease as the size of the cargo increases?

3. Why are four-fifths of the population of New York State in the counties bordering the Hudson River and Erie Canal?

4. What things would need to be known in order to determine accurately the amount of water power which could be developed in a given area?

5. (1) Account for the enormous amount of water power available in the Northern Pacific district, according to the table on page 443. (2) Why do the western tributaries of the Mississippi River afford more power than the eastern tributaries? (3) Why does the Northern Atlantic district (p. 443) furnish more water power than the Southern Atlantic?

6. Explain the fact that apples and other fruits are grown in great perfection and abundance on irrigated lands around Grand Junction, in western Colorado, while in the same latitude in western Nevada attention is given largely to hardier crops, such as grain, potatoes, and onions.

7. Account for the fact that legislation concerning the utilization of stream and ground waters is more advanced in western than in eastern United States.

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CHAPTER XVII

MOUNTAINS AND PLATEAUS AND THEIR RELATIONS TO LIFE

Mountains and plateaus have been referred to frequently in earlier pages. The more important points concerning their origin, their history, and their relations to human affairs are considered in this chapter.

Mountains

Distribution of mountains. As already noted, mountain ranges are situated in general toward the borders, rather than in the interiors, of the continents, and most of the longer and higher systems are not far from the edges of the greatest ocean basin. The settling of the ocean basins, due to the shrinking (partly through cooling) of the earth, may have been an important cause of the deformation which has occurred near the edges of the continental plateaus. This is, however, an unsolved problem.

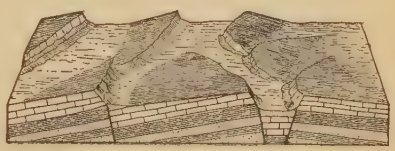

Fig. 337. Diagram of block mountains. (Modified after Davis.)

What is the age of these mountains, in terms of erosion?

What was the topographic age of the surface from which the mountains were formed? The evidence?

Leading types of mountains. (1) Fig. 337 shows several mountain ridges of one type, and suggests their origin. A plateau or plain was divided by giant cracks into a series of great blocks, which were displaced (*faulted*), the relatively elevated edges forming mountain ridges. The mountain ridges may be due to uplift, or to the sinking of the lower land adjacent to them, or to both. Such mountains are called *faulted* or *block mountains*. Block mountains in various stages of dissection occur in Oregon, Nevada, and elsewhere.

(2) Mountains consisting of a series of folds formed by compression from the sides are a common type. In some cases the folds

are open and symmetrical (Fig. 338); in others they are closed, unsymmetrical, and overturned. In some cases the arrangement of the beds is complicated by many faults, some of which may record a vertical displacement of several thousand feet (Fig. 339). The present topography of most folded mountains — for example, of

Fig. 338. Open, symmetrical folds in the Appalachian Mountains. Northeastern West Virginia. Length of section, about 12½ miles. The formation shown in solid black contains coal. (After U. S. Geol. Surv.)

the Appalachians and Juras — is not controlled so much by the original folding and faulting as by subsequent erosion and warping.

(3) Many of the higher isolated mountains are *volcanic cones* (p. 302; Fig. 340). Many mountains have been formed also by massive intrusions of lava which have domed or lifted the overlying beds high above the level of the surrounding country (Fig. 177). In many such cases the cover of sedimentary rocks has been partly removed by erosion, exposing the central core of igneous rocks (Fig. 341). Among the mountains produced chiefly by vul-

Fig. 339. Folded and faulted strata in the Appalachian Mountains near Bristol, Virginia. (After U. S. Geol. Surv.)

canism and subsequent erosion are the Henry Mountains of Utah, and the Park and Elk ranges (Fig. 342) of Colorado.

(4) There are many mountains which owe their existence simply to the resistance of their rocks, which have been left standing in bold relief by the removal of the surrounding weaker rocks. Many mountain peaks, aside from volcanic peaks, are of this origin. Pike's Peak, Colorado, is a notable example. The Catskill Mountains of southeastern New York are due to unequal erosion, where the resistance of the rock is not very unequal. They are really a dissected plateau. Various other maturely dissected plateaus of considerable relief are called mountains.

(5) Folding and faulting, vulcanism and unequal erosion all may be involved in the formation of lofty mountains. Many

Fig. 340. Mt. Adams from Trout Lake. (Copyright by Kiser Photo Co.)

mountains, furthermore, have had several periods of growth, between which the upraised beds suffered great erosion (Fig. 343).

The formation of mountains is an extremely slow process, probably occupying, for the greater ranges, hundreds of thousands or even millions of years. Many mountains appear to be growing now,— for example, the St. Elias Range of Alaska.

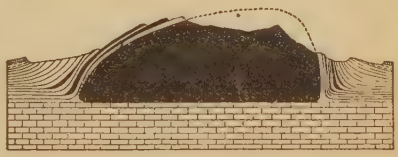

Fig. 341. An eroded laccolith. Cross-section of Mount Hillers, Utah, with ideal representation of the underground structure. Compare with Fig. 177. (After Gilbert, U. S. Geol. Surv.)

Destruction of mountains. All mountains are destroyed in time by erosion, unless renewed by vulcanism or uplift. Furthermore, the erosion of mountains commences as soon as they begin to rise, and continues throughout the long

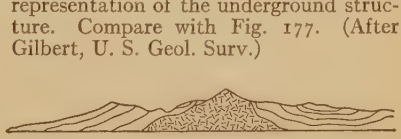

Fig. 342. Cross-section of Elk Mountains, Colorado.

period of their growth, as well as afterwards. As a result, no mountain due to vulcanism or *diastrophism* (crustal movements) ever had the full height which those processes would have given it, if unopposed by erosion. As already pointed out, many mountains have been several times nearly or wholly reduced and revived again. The length of the life of a mountain which has ceased to grow is determined largely by its height, by the resistance of its rocks, and by the character of the climate.

How does the steepness of many mountain slopes influence their erosion? Why is rock-splitting generally important on lofty mountains? When the slopes are not too steep, mountains may be covered with loose, angular fragments broken from the rocks beneath (Fig. 139). Even in arid regions, mountain valleys may

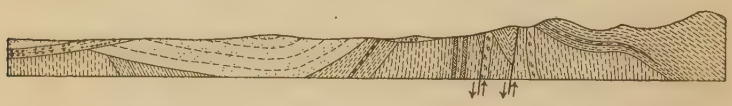

Fig. 343. Diagram showing structure of the beds in the region of the Santa Lucia Range, California. Length of section, about 11 miles. (After U. S. Geol. Surv.)

contain rushing torrents. (Explain.) In general, erosion by mountain streams is favored by steep gradients, but rapid cutting sometimes is opposed by the fact that the streams are clear (Why?). How does the absence of vegetation on many upper mountain slopes affect erosion? What conditions (1) favor and (2) hinder wind work on mountain heights? Glaciers are helping in the reduction of many lofty mountains (p. 392). In many other mountains with few or no glaciers now, the striking results (What are they?) of the work of former glaciers may be seen. Mountain scenery is due far more to the agents of land sculpture than to the forces of diastrophism.

The subdued and gentle slopes of the later life of a mountain are worn less rapidly than the steeper slopes of its earlier career, so that its old age may be longer than its youth and maturity combined. All lofty mountains are comparatively young, geologically speaking; old mountains have been worn low. While very old mountains are low, obviously not all low mountains are old.

Mountains as barriers. Mountains are barriers to the movement of animals and men, and to the spread of plants (Fig. 344). The effectiveness of a mountain barrier depends largely on its height, length, and width; on the number, height, and distribution of the passes; and on the number of ridges, and the steepness and character of their slopes. The high, massive ranges of the Pyrenees, Caucasus, and Andes mountains form very effective barriers. The Pyrenees

make the best natural inland boundary in Europe, shutting off Spain so completely from the rest of the continent that it is said frequently: "Africa begins at the Pyrenees." Although high, the Alps Mountains have several good passes, well distributed; accordingly, they

Fig. 344. Toltec Gorge, in the mountains of Colorado. Travel even along the valley is difficult. (Denver and Rio Grande Railroad Company.)

form a less serious barrier. The effect of many mountain barriers has been lessened by the building of wagon roads and railroads, the cutting of tunnels, etc. (pp. 470, 471). In other cases, mountains are crossed only by a few difficult trails, along which wares are taken on pack animals or by human carriers, trained by their environment to be climbers and packers.

Indians carry India rubber, in 150 pound loads, from the upper Purus and Madeira rivers up to the Andean plateau (15,000 feet above sea-level), whence it is transported on mules to the Pacific coast. Heavy bales of brick tea are carried by coolies over the mountains of western China to Tibet. Human beasts of burden carry the limited traffic of many other backward mountain regions.

For a long time, northern and central Europe was excluded by mountains from the culture of the leading Mediterranean countries. China is largely shut off from the rest of Asia by encircling mountains, a fact of much importance in connection with the isolated development and backward state of that country. The Appalachian barrier helped to confine the English colonies to the Atlantic seaboard for a century and a half. This favored the development of compact commonwealths, and permitted much more rapid progress along many lines than

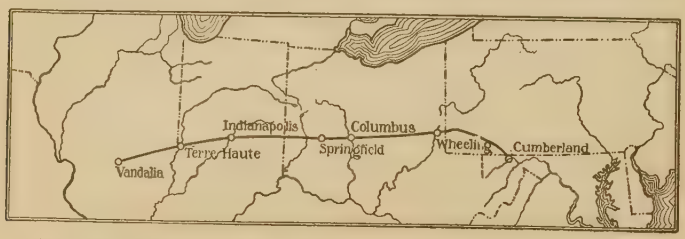

Fig. 345. Map showing course of Cumberland National Road.

would have been possible had the colonists spread themselves thinly over a vast area, after the manner of the French, who controlled the St. Lawrence gateway into the Interior. For years after the Revolutionary War, the Appalachian Mountains exerted a decentralizing influence, politically, which threatened the integrity of the Union (p. 419). The first great step in their conquest as barriers to trade and travel was taken when the Cumberland National Road was completed from Cumberland, Maryland, to the Ohio River at Wheeling, in 1817 (Fig. 345); the second when the Erie Canal was opened (1825). Though this canal did not cross the Appalachians, it afforded an easy route to the Interior; and the third and greatest, when four railroads were finished across them in the 1850's. It is noteworthy that these first trans-Appalachian railroads crossed the barrier at the north, where it is narrowest, lowest, and has most good passes. Though no longer a formidable barrier, these mountains still impose serious engineering and transportation problems on some of the railroads which cross them. Until the completion of the first transcontinental railroad (1869), travel across the western mountains and plateaus was so difficult that many people going to California chose the 13,000-mile voyage around Cape Horn, or the route by way of the Isthmus of Panama.

The difficulty of crossing high, rugged mountains gives great importance to notches or passes in their ridges. Many mountain passes are water-gaps or wind-gaps; their formation has been explained, and their relation to human affairs illustrated (pp. 358, 360).

Trails, wagon roads, and railroads all seek the lowest and most accessible passes (Fig. 346). They commonly enter the mountains along main valleys, and, where necessary, zigzag up the steeper slopes to the passes which serve as gateways through the central ridges (Figs. 347 and 348). In some cases, railroad companies have avoided the last part of the ascent by tunnelling the mountain below the pass.

South Pass (altitude, 8,230 feet), in central Wyoming, is the most important pass, historically, in the Rocky Mountains. Through it ran the famous Oregon Trail, along which many thousands journeyed to the grain lands of Oregon and the gold fields of California. Truckee Pass (7,017 feet above sea-level) affords a relatively easy route across the central part of the Sierra Nevada Mountains. It was used first by the California Trail, and is used now by the Southern Pacific Railroad. As the lowest gap in the Caucasus Mountains and the only one open throughout the year, the Dariel Pass is of much importance to Russia; through it runs the great military road to Tiflis. The Pass of Belfort, between the Vosges and Jura mountains, connects the Rhone and Rhine valleys, and with them has constituted since ancient times one of the most important routes of travel between the Mediterranean and North seas. The passes in the mountains of northwestern India have served repeatedly as gateways through which tribes and armies from central Asia have descended to plunder and conquer the people of the plains.

Fig. 346. Sketch-map of region about Hollidaysburg, Pennsylvania, showing the influence of mountain passes upon the course of wagon roads and railroads. (From Hollidaysburg Sheet, U. S. Geol. Surv.)

The difficulties of travel and communication in rugged mountains shut their inhabitants away from the outer world, helping to retard progress. Old customs, fashions, and manners of speech are likely to be preserved by mountaineers long after they have been abandoned by the people of the more open lowlands. Education is backward and the percentage of illiteracy high; much of the

Fig. 347. Road zigzagging up mountain slope in Switzerland. Rhone Glacier in middle background.

Fig. 348. Canyon of the Rio de las Animas Perdidas, Colorado. A "double-header" train creeping along a narrow ledge. (Denver and Rio Grande Railroad Company.)

simple clothing, furniture, etc., is home-made; trade in many cases is restricted to barter, involving only the absolute essentials of life; and social intercourse is restricted seriously, favoring the close intermarriage of families and the development of "clans." These conditions are illustrated well among the mountaineers of the southern Appalachians (Fig. 349). They do not exist, of course, in new mountain communities established by progressive people from out-

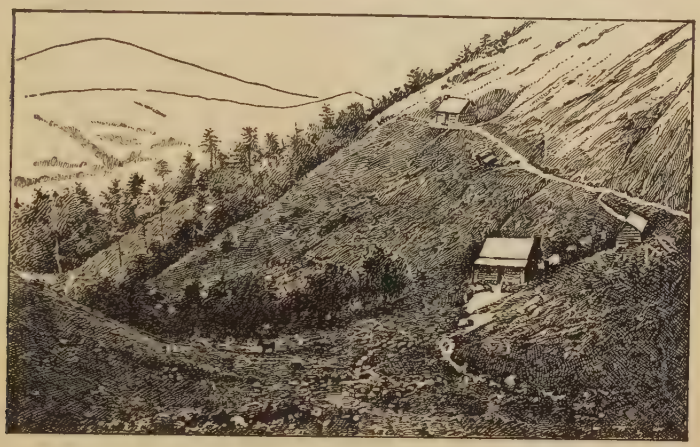

Fig. 349. Homes of mountaineers in the southern Appalachians.

side, and they have been changed greatly in some long-settled mountains (e.g., in the Alps) by the coming of summer visitors (p. 482), and in other ways.

Many mountains are important climatic barriers (p. 122), and the conditions of life on their opposite sides may be very different. The western slopes of the Sierra Nevada Mountains receive an abundant rainfall; to the eastward stretch broad deserts. Because most of its early mines proved disappointing, and the deficient rainfall prevented the extensive practice of agriculture, the population of Nevada was always small and fell from about 62,000 in 1880 to some 42,000 in 1900, less than that of the city of Akron, Ohio, at the same time. This was the penalty of its position to the leeward of high, rain-catching mountains. More recently, the population of Nevada has increased because of irrigation and the discovery of new mineral wealth. The contrast is even greater between the two sides of the

Himalaya Mountains; to the south are the crowded millions of India, to the north the scattered, nomadic tribes of Tibet. The difference here is not due wholly to the mountains, but largely to the great altitude of the plateau on the north side.

The settlement of mountains. Most lofty mountains are accessible with difficulty, and within them the conditions of life are hard. In general, therefore, the settlement of rugged mountains begins only after the more inviting neighboring lowlands have been occupied, and their populations are always relatively sparse. The areas of the Adirondack, Catskill, Alleghany, and other mountains in eastern United States were blank spaces on the earlier census maps (Figs. 437 and 439), and their populations are in most sections sparse even now (Fig. 442). A similar situation exists in the western mountains, the Rockies in 1900 containing only 0.8 per cent of the population of the country.

Mountain areas are settled first and most thickly in their larger valleys. Here the flatter land favors tillage, soils are thicker and in most cases more fertile (Why?), the climate is milder, and the trails of the upland are replaced by roads. The Shenandoah Valley and its southward continuation, the Valley of East Tennessee, were among the first areas to be occupied west of the Blue Ridge, soon forming a great island of settlement, with fertile farms and prosperous villages, in the midst of the mountain wilderness (Fig. 437). Similarly, the valleys of the upper tributaries of the Missouri River attracted the first permanent settlers into the Rocky Mountains of Montana.

The inhabitants of many mountain valleys in Europe and Asia are descendants of people who sought refuge there from their more powerful enemies. The Basques, who dwell in the western valleys of the Pyrenees, are an example. In other cases, the occupation of mountain strongholds has permitted people to dominate the adjoining lowlands, and levy tribute on their inhabitants. At the beginning of the Revolutionary War, four-fifths of the Cherokee Indians dwelt within the southern Appalachians, and from their mountain villages they repeatedly made sudden attacks on the frontier outposts of the whites.

Agriculture in mountains. Outside the valley bottoms, conditions are unfavorable to agriculture in high mountains, and in many places absolutely forbid it. Many slopes are too steep to be tilled, consisting either of bare rock or having here and there a thin

covering of soil which washes easily when cultivated; and with increasing height, the climate prevents the raising of crops and even the growth of trees and grasses (Fig. 350). Switzerland is largely mountainous, and only about 15 per cent of its area is arable land. Only 1/7 of the three Alpine provinces of Austria is tillable. Less than 1/6 of Japan can be cultivated readily. Such conditions mean a scanty food supply and a constant tendency toward over-population. As a result, there has been persistent emigration from many mountainous countries, such as Norway. These conditions mean also that in many long-settled mountain regions the cultivable land is farmed intensively in small holdings. Every effort is made to maintain the fertility of the soil, so that it may return large yields continuously. To this end, for example, the stock is herded closely at night in some regions, so that the manure may be saved for the land. Even from pasture lands where the stock roams by day, the manure is carefully gathered, in some of the mountains of Europe and Asia, and applied to the soil.

Fig. 350. Dwarf white pine at timber line in Sierra Nevada Mountains. (Fairbanks.)

In many mountain regions, where the level land has been developed fully, the slopes, too steep for agriculture by ordinary methods, have been utilized by the construction of terraces. Retaining walls are built one above another on the slopes, and the spaces behind filled in and covered with soil, which, in many cases, is brought by hand from considerable distances. In this way, successive tiers of nearly level benches are made. Terrace agriculture is practiced in parts of Arabia, India, China, Italy, Germany (Fig. 351), France, Switzerland, and other countries. (Why, in many cases, are the terraces built by preference on *south-facing* mountain slopes?) In the European countries mentioned, much terraced land is used for vineyards. Choice fields with bearing vines equal in price the best irrigated fruit lands of western United States (p. 448).

The crops which may be grown in mountains vary with the expo-

sure, the altitude, the rainfall, the character of the soil, etc. In general, the slopes of a lofty mountain present successive climatic zones to which plant life, and animal and human life as well, are adjusted. If such a mountain is situated in low latitudes, its slopes may afford conditions ranging from those of the Tropics to those of the Polar Zones (p. 38). In the Alps, the following changes may be noted: (1) In suitable places on the sides of the lower valleys there are vineyards, olive orchards, and mulberry

Fig. 351. Terraces along the Rhine Valley. (Butts.)

groves worked intensively by a relatively dense population. (2) Higher up, these are replaced by grain fields and pasture lands, interspersed with forests of deciduous trees. This zone is less productive and settled less thickly than the first. (3) Still higher, hardy evergreen trees prevail, the proportion of useless land increases, only the hardiest grains are grown (up to about 5,300 feet) in small fields by the sparse population, and most of the land with soil is devoted to pasturage and to the growing of hay for the winter feeding of the stock. (4) Above the "*tree-line*" (the upper limit of tree growth is about 7,600 feet) is a belt in which some of the slopes bear grass, where cows, sheep, and goats are pastured for a short time in summer. (5) Finally, there is a waste of bare, rocky slopes and snow-fields, unoccupied by life which is useful to man.

Stock-raising in mountains. Stock-raising is an important mountain industry in many countries, for slopes too steep or too rocky to be tilled, or too high to permit cultivated crops to ripen,

may afford pasturage (Fig. 352). As suggested above, pasturing stock and growing feed for its consumption during the winter constitute a leading industry in the higher Alps. More than half the productive area of Switzerland consists of pasture land and hay land. In spring, herdsmen take their cattle, goats, and sheep from the villages in the valleys up to the high pastures, advancing, as the growth of the grass permits, close to the snow-line (Fig. 353),

Fig. 352. Sheep grazing on a mountain side in Holy Cross National Forest, Colorado. (U. S. Forest Service.)

where the grazing season may last only six or seven weeks. In autumn, the flocks and herds are driven back by stages to the lower valleys, where they are fed in stables during the long winter. As in various other countries, most of the high pastures of Switzerland are not owned privately, and their use is regulated by custom or law. The raising of sufficient hay and other fodder for the winter feeding is perhaps the most difficult part of the industry, and this requires arduous labor during the summer. For many years butter and cheese have been leading products of Switzerland, and emigrants have taken the industry to various other countries. For example, making "Swiss cheese" is an important industry in certain counties of Wisconsin. Stock-raising of one kind or another is a leading occu-

pation in the mountains of Norway, Germany, central Asia, western South America, western United States, and elsewhere.

In western United States great numbers of cattle and sheep feed on the grass of the public domain. The use of the unreserved and unappropriated portions of the public domain is free and unrestricted. While this has had its advantages, it has resulted, at many times and places, in the overstocking of the range, and a decrease in its capacity. Some system of regulation is likely to be adopted soon. Grazing in the National Forests is regulated now. The Government limits the

Fig. 353. Summer grazing in the High Alps.

total amount of stock for each forest, and the superintendent of the forest divides the range among the applicants, giving the nearby settlers, with little stock, first consideration; then, in turn, the local residents with larger herds, who have used the range regularly, the regular users from a distance, and the owners of transient stock. A small fee is charged for the use of the range. During a recent year more than 25,000 grazing leases were issued, under which great numbers of sheep (Fig. 354), cattle, and horses were pastured.

Mining in mountains. Many mountains contain valuable ore deposits, and mining is one of the most distinctive of mountain industries. On the other hand, many mountains are not known to contain ores or mineral matter of commercial value, while various ores, and numerous mineral substances which are not ores, are mined in plateaus and plains. The original source of most of the valuable metals appears to have been the igneous rocks, and massive intrusions of the latter form the central cores of many mountains.

The metals probably were scattered widely through the igneous rocks to begin with, and were slowly concentrated into *ores* in veins, largely by ground-waters (p. 331). These veins are, for the most part, in or near the igneous rocks. Many of them have been exposed, and so made available to man, by erosion. The iron and copper of the Lake Superior region occur in the rocks of old, worn-down mountains. Much of the gold mined in the West has come from

Fig. 354. Sheep grazing in the San Juan National Forest, Colorado. (U. S. Forest Service.)

igneous rock, and from the immediate surroundings of great intrusions of lava. In northeastern Pennsylvania the folding of beds of rock containing layers of coal helped to change the latter into "hard" or *anthracite* coal. Much of the coal of this region was destroyed later by erosion, but much was preserved in the down-folds of the mountains (Figs. 355 and 338). More than 80,000,000 tons of this coal are mined yearly at Scranton, Wilkesbarre, and other points, and much of it is sent throughout eastern and central United States.

Cities have grown quickly from rude mining camps following the discovery of rich mineral deposits (Fig. 356). Thus in the late 1870's Leadville, Colorado, became a city of 15,000 people in a few months, though in a sage-brush valley then difficult to reach, and at an elevation of 10,000 feet. In 1880, it shipped more than

a million dollars worth of gold, silver, and lead each month. Again, important mineral deposits may help to concentrate a dense urban and industrial population about the borders of the mountains in

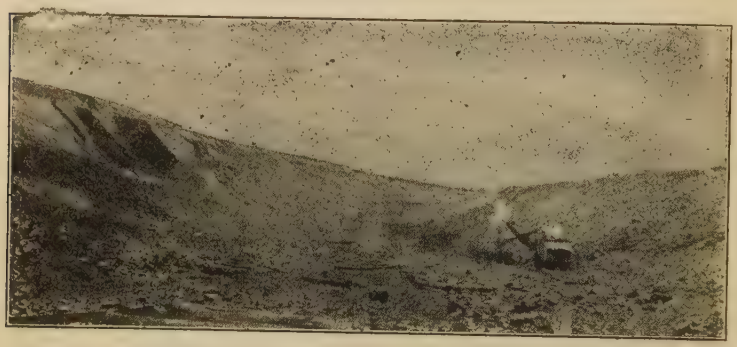

Fig. 355. Coal stripping near Hazleton, Pennsylvania. The coal (shown at the left) occurs in down-folded (*synclinal*) beds. Steam shovel for loading coal at right. (Roorbach.)

which they occur, as in the case of the Pennine Mountains of north-central England, and the Erz (meaning *ore*) and Riesen ranges of Germany, where mining has been carried on for many years.

Fig. 356. Bisbee, Arizona, a city which grew up about copper mines.

Mountains as forest reserves. The slopes of many mountains have been left largely in timber, because unsuited to agriculture, and various mountain ranges now support important lumber

industries (Fig. 357). The relation of mountain forests to the flow of streams rising in them, and to the problems of navigation, water power, irrigation, and soil erosion has been noted (pp. 269, 444, 455). These problems, together with the need of insuring a permanent lumber supply, have led various countries to regulate the use and cutting of mountain forests, and to provide that certain areas remain forest-covered.

Fig. 357. Modern lumber mill in the Sierra Nevada Mountains, California. (U. S. Forest Service.)

Japan has many steep volcanic mountains, whose slopes, if uncovered, would be eroded rapidly by the abundant (Why?) rains; this helps to explain the fact that nearly $^3/_5$ of the country has been left in forest reserves, although the nation is in great need of more farm land. Among European countries, Germany, Switzerland (Fig. 358), and France have skillfully-managed forest reserves on mountain slopes. France is said to have more torrential streams than all the rest of Europe, and forest destruction on mountain slopes in earlier years increased greatly the number and violence of floods. In recent years the government has spent large sums in reforestation. Switzerland gave attention very early to the preservation and care of mountain forests; in some places forest regulations were in force 600 years ago. Some of the Mediterranean countries show the evils which may follow the cutting away of mountain forests. In Dalmatia, for example, mountain slopes once forested consist now of bare rock, and are of little use to man. In parts of eastern and northeastern China the forests are gone, and one may travel hundreds of miles without seeing a single grove on the hill sides. Even the undergrowth has been destroyed, and in places all grass and other vege-

tation suited to the purpose are gathered for the cattle, or eaten by goats and sheep.

Serious results have followed: (1) Heavy rains cause sudden and violent floods. Valleys usually without streams may be occupied suddenly by torrents which destroy bridges and buildings, ruin fields, and then disappear entirely within a few hours. (2) In many places not enough water enters the ground to keep the water table sufficiently near the surface for the good of plants. Farmers irrigate where they can, and grow plants suited to dry conditions, but over large areas they are unable to grow anything. (3) Erosion has been increased enormously (Fig. 143). Large lowland areas are covered with coarse waste, and much fine material is swept into the sea. (4) Timber is at a premium. In the western mountains forest destruction is less advanced, and travellers report meeting long lines of coolies carrying boards down to the plains, where they are worth the equivalent of $2 to $3 each, a value which restricts their use to special purposes, such as making coffins.

Fig. 358. Mountain slopes in Switzerland, kept under a forest cover. (Doseff.)

Most of the National Forests of the United States (p. 455) are in the mountainous districts of the West (Fig. 336), where the greater part of the timber is found on the mountain slopes because the latter receive more rain than the surrounding plateaus and plains. Congress provided recently (Feb., 1911) for a National Forest in the southern Appalachians, where the maintenance of a forest cover on many of the slopes is of great importance (pp. 275, 342).

Mountains as pleasure resorts. The cool, invigorating summer climate and beautiful scenery of many mountains lead thousands

of lowland dwellers to visit them yearly. The mountains of New England, the Adirondacks, Catskills, and parts of the Alleghanies, are readily accessible to the more densely settled northeastern part of the United States, and contain many popular resorts. With the growth of population in western United States, the mountains of that section probably will be visited more and more.

Most of the National Parks (Fig. 359) and National Monuments are in the West, and a number of them contain mountains or portions of mountains of unusual beauty and interest. The National Parks, of which there are 13 in continental

Fig 359. Map showing distribution of National Parks. (U. S. Dept. Int.)

United States, were created by Congress, and serve various purposes; they are intended especially to be "play-grounds for the American people." In 1905 the President was given power to set aside from the public domain as National Monuments any "historic landmarks, historic or prehistoric structures, or other objects of historic or scientific interest." There are now more than twenty National Monuments, of which the Mount Olympus, Washington, and Grand Canyon, Arizona, monuments are largest.

The Alps, situated in the midst of densely settled countries, are the most beautiful mountains in Europe, and have come to be perhaps the greatest summer resort in the world. Hundreds

of hotels (Fig. 360) depend upon the tourist trade, and the entertainment of visitors has become almost a national industry.

Other mountain resources and industries. Fur-bearing animals constitute an important resource of some mountain regions. They were once a resource in many others where they have been nearly exterminated.

From about 1807 to the middle of the century, the fur trade in the Rocky Mountains of the United States was of great value. Trading posts were established at commanding points among the mountains and along the larger rivers

Fig. 360. A summer hotel in the High Alps.

flowing eastward from them, at which a driving business was done. St. Louis was the great depot and outfitting point of the trade. The trappers and traders were the pathfinders of the West. The fur trade is still of some importance in the mountains of western Canada.

We have noticed already that many isolated mountaineers are forced to make most of their own clothing, implements, utensils, etc. (p. 471). In addition, many mountain peoples make special articles of superior quality for sale. In this way they eke out a living, and find employment during the winter months when most outdoor activities are suspended. From wood, metals, wool, or other raw material at hand, they make artistic wares which are suited to mountain transportation, and command ready sale. Such are the carved wooden wares of the Swiss, and the lace made by some of the Italian mountaineers.

Many mountain streams afford abundant water power (pp. 383, 393, 444) which will be used increasingly in the future. In most cases, however, much of the energy will be carried outside the mountains in the form of electricity, to be used in the lowlands.

Plateaus

Distribution. As stated elsewhere (p. 37), large plateaus occur for the most part in three classes of situations. (1) Some of them are between a lower plain on one side and higher mountains on the other, (2) some are between mountain ranges, and (3) some rise abruptly from the sea, or from narrow coastal plains.

Origin. Plateaus are formed in various ways. (1) Some have been built by successive lava flows, like the Columbian Plateau of the Northwest (Fig. 176) and the Deccan Plateau of India. (2) Adjacent land may have been worn low or warped down, leaving a plateau. (3) The plateau may have been warped or faulted above its surroundings.

The erosion of plateaus. Like mountains, all plateaus will be worn down to lowlands, if not made high again. Mature plateaus are table-lands well dissected by streams; the surface is carved into hills (or mountains) and valleys (or canyons), and slope and relief are at a maximum. Some dissected plateaus are called mountains (e. g. the Catskills, p. 466). In one sense there are no old plateaus, for, when worn low, they are plains.

Conditions of life on plateaus. The conditions of life on high, dissected plateaus are much like those in mountains situated similarly (pp. 471–481), while the conditions on many low plateaus resemble closely those on neighboring plains (Chapter XVIII). Large, mountain-rimmed plateaus in continental interiors are, in general, deserts, and subject to great ranges in temperature. Accordingly, they are settled sparsely. Farming is confined for the most part to the slopes of waste at the bases of rain-catching mountains, where water may be led from the withering streams for use in irrigation. The greater part of such plateaus is uninhabited, save by bands of wandering nomads, as in Central Asia, or by occasional ranchmen whose cattle and sheep graze on the thin and scattered growth of grass, as in parts of western United States.

The habitability of a high plateau is influenced greatly by its latitude; while such a plateau is cold and uninviting in the Temperate Zone, it has a temperate climate in the Tropics, where, if other

conditions are favorable to occupation, it may have a population much denser than that of the neighboring lowlands.

Nearly three-fourths of the people of Bolivia live at altitudes of 6,000 to 14,000 feet, and of the nine most thickly settled provinces, five are at elevations greater than 11,000 feet. Three-fourths of the population of Ecuador are found in the plateau basins of the Andean highlands, at an average elevation of 8,000 feet. In Peru there is a comparatively dense plateau population. There is a striking contrast also between parts of the cool plateau and the hot lowlands of Mexico. The former have relatively dense and progressive populations, while the latter are settled sparsely by backward Indians. In higher latitudes, plateaus for various reasons are in general settled much less densely than the neighboring plains, as already indicated. The Great Basin and Columbian Plateau of western United States each contained, in 1900, only 0.5 per cent of the population of the country. In these regions the population numbered only 1.6 and 3.2 persons, respectively, per square mile. The sparsest population of Great Britain is found in the Highlands of Scotland, the county of Sutherland having only 11 inhabitants per square mile.

Questions

1. (1) In what stage of erosion are the mountains shown in Fig. 361? (2) Does the picture indicate (certainly, probably, possibly) anything concerning the character of the rocks? (3) How will the slopes of these mountains be changed in the future?

Fig. 361. Sketch of mountainous region.

2. (1) Compare and contrast the climate of the mountains and plain shown in Fig. 362. Why the differences? (2) What work are the streams doing in the mountains? On the plain? Reasons in each case? (3) What kinds of soil would you expect to find on the plain just west of the mountains? Why? (4) What does the map suggest concerning the chances for successful agriculture in the different parts of the area?

3. (1) Why is there a cliff on the slope shown in Fig. 363? (2) What was the origin of the rocks of which the cliff is composed? (3) How and by what agents will the character of the cliff be changed in the future? (4) Account for the difference in the amount of vegetation on the upland and lowland. (5) Will soil form quickly or slowly on the talus slopes? Why?

4. Compare and contrast the relations of mountains to the life of (1) primitive and (2) advanced peoples.

5. What probably would have been the effect upon the development of the United States had the Appalachian Mountains been equal in height to the Rockies or Sierra Nevadas of to-day? What if the western mountains had been as low as the Appalachians?

6. Account for the fact that houses in arid plateaus often are built with flat roofs and thick walls.

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Fig. 362. Portion of Paradise, Nevada, topographic sheet. Scale 4 miles per inch. (U. S. Geol. Surv.)

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Fig. 363. Cliff in eastern part of Bighorn Basin, Wyoming. (Darton, U. S. Geol. Surv.)

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See also list of textbooks on page 312.

CHAPTER XVIII

PLAINS AND THEIR RELATIONS TO LIFE

Origin and classes of plains. Various types of plains have been discussed in previous pages, and some of their relations to human affairs noted. Rivers make *flood-plains* (p. 364), *delta plains* (p. 372), and *peneplains* (p. 351). The ancient ice-sheets covered large areas of northern United States and Europe with drift, forming *drift plains* or *glacial plains* (p. 398). The floors of extinct lakes form many nearly flat *lake plains*, especially in glaciated regions (p. 400). Most lake plains are small.

Extensive plains, like the Atlantic and Gulf coastal plains of the United States and the vast interior plain which stretches from the Appalachians to the Rockies, cannot in most cases be put in any of the above classes. They commonly contain many smaller plains of several or all of the types mentioned. In general, extensive coastal plains are former marginal sea-bottoms, exposed either by elevation of the land or by lowering of the sea. Coastal plains may also be peneplains, or the result of the filling of a shallow sea border by wash from the land. Large interior plains are either areas once high but now worn low, or, in a greater number of cases, they are former coastal plains now separated from the sea by newer land. The changes produced on plains by erosion were discussed in Chapter XV.

Distribution of extensive plains. Most of the extensive plains of the world are in the northern hemisphere. The northern parts of the large plains which border the Arctic Ocean are of little value to man, but there are vast, fertile plains in the north temperate zone which are of great importance in the life of the world. The southern continents are unfortunate in having their most extensive lowlands within the tropics, where climatic conditions retard human progress.

General advantages of plains. From the standpoint of human occupation, plains which possess a favorable climate have distinct advantages over mountains and plateaus. In general, the slopes

of plains are gentler, their soils thicker and more fertile, and they have a much smaller percentage of useless land. Their advantages of climate, soil, and topography make plains the great agricultural regions of the world. In this connection it should be remembered that agriculture is the basis of all permanent advance in civilization. Movement is relatively easy on plains, and difficult in mountains (p. 468). This means that commodities and ideas circulate more readily, and that trade and culture develop more rapidly, among lowland people. There is a constant exchange, conflict, comparison, and accumulation of the ideas of many — a continual competition which spurs to progress. In mountains, a great variety of conditions may be found within a small area, while on plains, similar conditions may prevail over large areas. It follows that most occupations of plains have a much wider distribution than those of mountains. The effect of thin air on the human body (p. 45) helps to restrict man to relatively low lands.

Because of the fundamental advantages of lowlands for agriculture, trade, and intercourse, the great majority of the people of the world live on them. The relatively dense populations of the favored lowlands of the United States are shown by Fig. 442. The accompanying table shows the percentage of the total population of the United States at various altitudes in 1880 and 1900. In both years, more than 9/10 of the people lived at elevations of less than 1,500 feet. While this reflects the fact that most of the people of the United States live on plains, it will be remembered that there are plateaus and mountains lower than 1,500 feet, while a part of the Great Plains is much higher.

Altitude	Per cent, 1880	Per cent, 1900
Below 100 feet	15.1	15.9
100– 500 feet	23.1	21.8
500– 1000 feet	40.5	38.7
1000– 1500 feet	14.6	14.7
1500– 2000 feet	3.5	4.1
2000– 3000 feet	1.6	2.1
3000– 4000 feet	0.2	0.5
4000– 5000 feet	0.3	0.7
5000– 6000 feet	0.3	0.6
6000– 7000 feet	0.3	0.4
7000– 8000 feet	0.2	0.2
8000– 9000 feet	0.1	0.1
9000–10000 feet	0.1	0.1
10000–and above	0.1	0.1

Contrasts among plains. Apart from their mode of origin, plains differ in many respects. Thus they may be large or small, high or low, rough or smooth, forested or treeless, fertile or infertile, wet or dry, and in hot, temperate, or cold regions. Furthermore, all gradations occur between the extremes indicated. These differences affect human interests in important ways, many of which have been noted.

Relatively small plains protected by natural barriers, rather than large, open ones, favor early progress in civilization. A restricted area hastens advance to the agricultural stage (Why?), and as the population increases in density, laws and customs are developed in the attempt to overcome the friction which goes with crowding. The isolated and protected plains of Greece possessed many advantages for early progress. On the other hand, all parts of a vast plain, such as that of Russia, are open to attack; it is easy for the people to scatter in search of game and other food; and the natural food supply may be sufficient to postpone indefinitely further progress. Extensive plains, such as those of central United States, afford excellent conditions for the further growth and development of a people already advanced in civilization. This is especially true where, as in the case cited, such plains have varied geographic conditions and resources in their different parts. The vast plains of Russia lack such diversity to a marked degree, and this is held by many to have been an important factor in producing the monotony characteristic of Russian country life.

Climate is the most important factor affecting the life of extensive plains, and the larger plains of the world are so distributed with reference to climate that the conditions of life in them may be discussed briefly under the following headings: (1) Life in well-watered plains of middle latitudes. (2) Life in semi-arid plains. (3) Life in desert plains. (4) Life in Arctic plains. (5) Life in humid plains of low latitudes. The more important direct effects of various types of climate on life were discussed in Chapters IX, X, and XI.

Life in Well-Watered Plains of Middle Latitudes

The middle-latitude plains having adequate rainfall are the seats of advanced civilizations, and some of them support dense populations. The soil is the most important natural resource of these plains, and agriculture is the most wide-spread occupation. On the whole, they have less than certain highlands in the way of forests, minerals, and water power, though they are by no means without these resources. Lumbering and mining are carried on at many points, and commerce and manufacturing are developed

highly in the more densely settled sections. In the complex life of these regions, the influence of geographic conditions is less apparent and less direct, but not less important, than in the simpler life of the grasslands and deserts.

Differences in the character of the soil, in the form of the land, in conditions of drainage, etc., may be reflected in the distribution and occupations of the people. The influence of variations in soil is especially great, and may be observed in many places. In the glaciated plains of northern United States, various kinds of soil may occur within a small area, in places even within the limits of a good-sized farm. Here the intelligent farmer is likely to devote each type of soil to the particular use or uses to which it is adapted. In other places, the character of the drift over several or many square miles is determined by the nature of the underlying rock, so that, for example, an area of sandy drift, over sandstone, may lie beside an area of limey clay, over limestone. In such a case in a certain region in south central Wisconsin, the condition of the people in the two areas is very different. The area of fertile, limey-clay soil is said to have been settled by people of greater means, while the sandy area was occupied by poorer people not in a position to choose. The initial difference appears to have increased. In the one case, there are attractive homes that have modern conveniences, there are large barns, many windmills, improved roads, and many well-equipped schools; in the other, many of the buildings are old and unpainted, few farms have windmills, roads are poor, and some of the schools are in an unsatisfactory condition.

The influence of soil on the distribution and activities of people may be seen on a larger scale in various parts of the Atlantic and Gulf coastal plains. In Alabama, the northern part of the state is underlain by old rocks (Fig. 364). This section was land when the area of the coastal plain was a marginal sea-bottom. Material washed from the old land helped to build the strata of the coastal plain. East and west across the middle of the state is a low, nearly level belt of rich soil, weathered from the soft underlying limestone. This is the inner part of the coastal plain. From its southern edge the ground rises rather abruptly some 200 feet, because of the outcrop of more resistant beds, and then slopes gently southward to the coast. The soils of this outer belt are much poorer than those of the inner lowland, except along the bottoms of the larger valleys, where there are deep, fertile loams. The development and present life of the state cannot be understood apart from these soil belts. The first American settlers, typical log-cabin pioneers, settled for the most part in the rich inner lowland and along the fertile valley bottoms. Later, this was seen to be the section best suited to the growth of cotton, and many of the earlier settlers were pushed by the slave-owning planters north into the foothills of the mountains, or south into the sandy areas of the outer coastal plain. The inner lowland contained the largest number of slaves at the time of the Civil War (Fig. 365), and more than $3/5$ of its present population are negroes. Here also are the cities of Montgomery and Selma. The outer zone of the coastal plain always has had a relatively sparse population, except along the larger valleys. There are still extensive pine forests where lumbering, the making of turpentine, and grazing are leading industries. Mobile is the only important city in this section of the state. It has a harbor at the drowned mouths of the leading rivers of the region, and is the natural gateway into the state from the south.

In the Netherlands, the Frisian, Saxon, and Frankish elements of the population for the most part occupy contrasted soil areas in the western and northwestern, eastern, and southern parts of the country, respectively. "All the types have maintained their differences of dialect, styles of houses, racial character, dress and custom." The soil belts of the ancient coastal plain of eastern England are said to have influenced in important ways the development and life of the region.

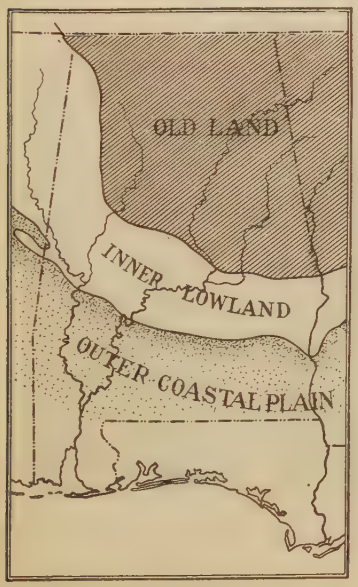

Fig. 364.

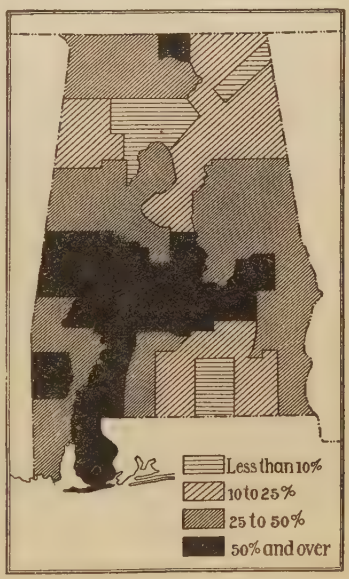

Fig. 365.

Fig. 364. Map showing principal physiographic provinces of Alabama.

Fig. 365. Map showing distribution of slaves by counties in Alabama (1860). Figures in legend indicate percentages of the total population.

Life in Semi-Arid Plains

Large semi-arid plains occur in the belt of the trade-winds, where some of them merge into deserts, as in northern Africa and Australia. Others lie in continental interiors to which the dominant winds come robbed of most of their moisture in passing over mountains, as in the case of the steppes of western Asia and the Great Plains of the United States. The scanty rainfall of such plains or its unfavorable distribution prevents the growth of most trees except

along the streams, and restricts useful vegetation to quick-growing grasses and a few other hardy types of plants.

Hunting tribes and pastoral nomads. Under primitive conditions, the inhabitants of the grass lands of the world derive their support from flocks and herds, or depend on the chase, like the buffalo-hunting tribes of earlier years on the Great Plains (p. 496). Both the pursuit of game, and the frequent need for fresh pastures with new supplies of water, condemn the people to a nomadic life,

Fig. 366. Home of native nomad of Argentine Patagonia. (Harriet Chalmers Adams.)

and so help to retard progress in civilization. The dwellings must be such that they can be moved easily (Fig. 366), and in many cases they are tents of skins, or of felt made from wool; personal effects and household utensils are few and light; and among pastoral nomads the most desirable form of wealth is flocks or herds, which transport themselves.

The movements of many pastoral tribes are regulated by the seasons. In some cases, their flocks and herds are driven in summer into the highlands, thus escaping from the hotter plains and utilizing more of the pasturage. The Kirghiz of Russian Turkestan regularly take their flocks in summer up into the Altai Mountains, and bring them back to the lower lands in winter. Again, the more abundant grass and water of the rainy season may permit the people to gather

in considerable groups in desirable localities, while in the dry season they are forced to scatter widely, to secure food for their animals.

Less strikingly than the men of the desert (p. 502), the pastoral nomads of semi-arid plains have always been marauders and conquerors. Under favorable conditions, their growing herds and flocks require more and more pasture, and from time to time compel them to move beyond the boundaries within which they formerly had roamed. On the other hand, severe and protracted drought, resulting in reduced pasturage and a failing water supply, or disease among their animals, may reduce them to the verge of famine, and drive them to pillage and conquest. The active, hard life of the pastoral nomad serves as an excellent training for military service. Constant exposure and exertion develop endurance and bravery, while the frequent moving of tents and flocks from one place to another results in many cases in an effective organization, well suited to military needs. Mounted on horses or camels, the nomads are able to make swift attacks on the people of neighboring districts, and to retreat as quickly with their booty. History furnishes many examples of the lasting antagonism between the militant nomads of dry plains and the peacefully inclined farmers of moister lands. For centuries, portions of agricultural Russia were pillaged repeatedly by hordes of horsemen from the southeastern steppes, and the Great Wall of China was built as a protection against pastoral nomads.

In general, it may be said that the conditions of life in semi-arid, grassy plains rarely, if ever, permit the native tribes occupying them to develop more than a low form of civilization.

Use of semi-arid plains by civilized people. Even where civilization is advanced, plains that are too dry for agriculture by ordinary methods are devoted largely to the grazing industry. Vast semi-arid areas used in this way occur in the United States, Argentina, Australia, and Russia. More than $1/6$ of the world's cattle and nearly $1/10$ of the world's sheep are owned in the United States. By no means all these animals are found either in plains or in regions of deficient rainfall, but under modern conditions such districts constitute the typical grazing areas.

By means of irrigation and special methods of cultivation, agriculture doubtless will be extended greatly in the future in semi-arid regions.

The Great Plains. The history of the western portion of the Great Plains illustrates many of the conditions of life in semi-arid

regions. Until after the Civil War, these plains were occupied by Indians dependent for a living on the great herds of buffaloes. The practical extinction of the buffalo and the rounding up of the Indians on the reservations opened the region to the cattle industry. In the drier sections, attempts to farm by ordinary methods have been generally unsuccessful, though here and there streams and wells furnish water for irrigation (p. 498). Within the last few years, "dry farming" (p. 498) has replaced the grazing industry in many places.

As already indicated, the buffalo was the most important factor in the lives of many Indians of the Great Plains. The chase required many quick moves, and this helped to keep the family relatively small, the houses light and portable, and to restrict the personal equipment and household utensils to a few essential articles. Individual ownership of land was unknown among some of the tribes. Man was the exclusive breadwinner, and probably partly for this reason woman occupied a relatively low position. The mythology of the Indians was tinged by their hunting and military habits. The chiefs attained their positions because of their skill as hunters or warriors, and the organization of the tribes tended toward the development of an aristocratic type of government. With the disappearance of the buffaloes, the hunting tribes lost their chief support, and became dependent on the white man. Great numbers of buffaloes were killed as food for the construction gangs of western railroads, and for their hides, in great demand in the East for robes, belting for machinery, and other purposes. They practically disappeared from the southern plains in the middle seventies, and from the northern plains a few years later.

The stock-raising industry of the Great Plains began in Texas and spread northward. Cattle were introduced into Mexico by the Spaniards about 1525, and before the Revolutionary War there were large cattle ranches north of the Rio Grande. In the middle 1850's, most of Texas was "a vast, unfenced feeding ground for cattle, horses, and sheep." At the close of the Civil War, cattle were very cheap in Texas, but brought high prices and were in great demand in the northern cities. As a result, the practice was developed of driving cattle northward in great herds to shipping points on the railroads that were then building across the Great Plains in Kansas and Nebraska. The "cow towns," as the shipping points were called, were established beyond the farming frontier, preferably where there was a good supply of water and grass. The business shifted west and south with the advancing railroads, keeping in front of the farming zone. Some of the best known "cow towns" were Abilene, Newton, Wichita, Great Bend, Dodge City, and Hayes City (now Hays), all in Kansas, and Ogallala, in Nebraska (Fig. 367). The banner year of the Texas cattle drive was 1884, when 4,000 men, equipped with 30,000 horses, drove 1,000,000 cattle out of the state. Soon after, the drives were rendered unnecessary by the extension of railroads, which took the stock to market in much less time and usually in better condition. The stocking of the northern lands occurred, for the most part, after 1870, and before the close of another decade the business had spread to the Canadian boundary. For a time, large returns were realized from feeding cattle on the public grass. Many people accordingly entered the business,

and in numerous places the range was overstocked and the pasturage injured. One result of this in many places was the introduction of sheep, which can live on pasturage which will not support cattle. The conflicting interests of cattlemen and sheepmen have caused much trouble in some of the grazing states, and have sometimes led to bloodshed. The development of the grazing industry on the Great Plains had an important influence upon the growth of the slaughtering and meat-packing industry in Kansas City, Omaha, St. Louis, Chicago, and (later) South Omaha, from which meat products were sent to the urban and industrial centers of the northeastern states and Europe. The number of cattle in Wyoming, for example, increased from 11,000 in 1870 to 521,000 in 1880, in which year 60,000 were sent to Chicago and an equal number to Kansas City. During the same time, the number of sheep in Wyoming increased from 6,000 to 450,000.

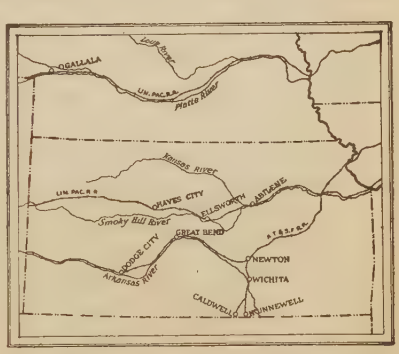

Fig. 367. Map showing principal "cow towns" of Kansas and Nebraska.

As the frontier of agricultural settlement pushed westward into the grazing area, the interests of farmers and stockmen were often at variance, giving rise to important legal problems. Thus for a time cattle roamed at will, and the pioneer farmer had to fence his land to protect his crops. In 1873, Texas solved this problem by passing a trespass law, under which the stockmen were held responsible for damage done by their animals to crops, even if the latter were not fenced in. This law facilitated the spread of the farming industry. Many of the cattlemen bought land and fenced it, or employed "line-riders" to watch their stock. Many who did the former, substituted sheep for cattle. Those unwilling to fence or line-ride, pushed away from the agricultural settlements into the Panhandle of Texas. These facts illustrate how conflicting uses of the land may acquire political significance, and how, in turn, legislation may affect the distribution of industries. They also afford an additional illustration of the chronic antagonism between pastoral and agricultural peoples (p. 495).

In 1880, the Great Plains west of the 98th or 99th meridian were occupied only by scattered stockmen, except along some of the larger valleys (Fig. 368). A few years later thousands of farmers moved to the High Plains, and began to grow wheat for export, using the seed and methods which they had employed farther east, where the rainfall is greater. The population of Kansas increased 250,000 between 1885 and 1888, largely in the western portion (Fig. 369). The agricultural invasion began because of heavy rains in the middle eighties, and was kept up for a few years by the advertising of railroads and the activity of town-builders and land-dealers. Then came several very dry years, and thousands were starved out of the region. Kansas lost some 200,000 people, and the western parts of Nebraska, the Dakotas, and the eastern part of Colorado were affected similarly (Fig. 370). Millions of acres returned slowly to grass, and within a few years the sites of hundreds of "cities" were marked only by parallel rows of cellar excavations, iron

hydrants at corners, and the like. Within the last few years, another agricultural invasion of the High Plains has been in progress. A series of unusually wet seasons, the activity of land companies, and the introduction of agricultural methods adapted to semi-arid conditions have been the leading causes. The outcome is still uncertain, but is not likely to be so disastrous as the first settlement, because men know better now how to make use of dry lands.

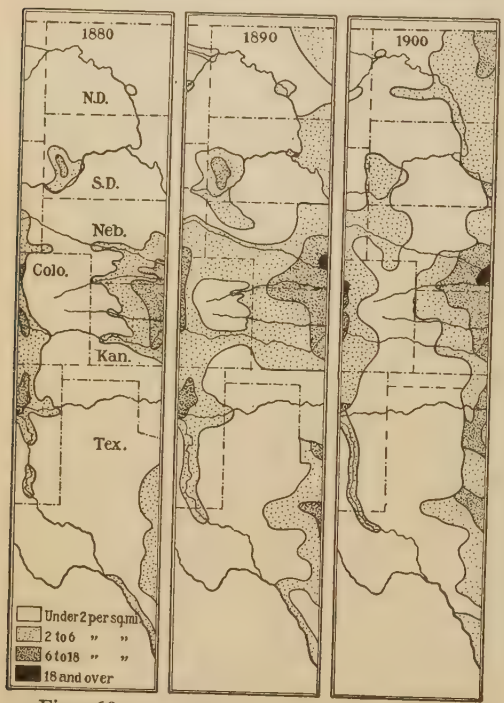

Fig. 368. Fig. 369. Fig. 370.

Figs. 368, 369, 370. Maps showing distribution of population on the western Great Plains in 1880, 1890, and 1900.

The principal uses to which the semi-arid parts of the Great Plains will probably be put in the future may be suggested briefly. (1) Farming by irrigation will be extended somewhat, but the greater portion of the higher plains appears to be non-irrigable because of insufficient water. The amount of water available from all sources constitutes but a small fraction of what would be required to irrigate all the land. There are government irrigation projects on the Arkansas, Platte, Belle Fourche, and Missouri rivers (see Fig. 331). Much water is obtained from artesian wells in the Dakotas, and small artesian basins are known farther south. Ordinary wells also supply some water for irrigation. (2) "Dry-farming," especially with hardy, drought-resisting plants (p. 276), promises much more than irrigation for the region as a whole. "Dry-farming" scarcely can be said to have passed the experimental stage, and how large an area can be dry-farmed successfully is quite uncertain. As already pointed out (p. 99), "dry-farming" seeks (a) to get the largest possible proportion of the rainfall to enter the ground, and (b) to reduce to a minimum the loss of water by evaporation from the soil. (3) Stock-raising, and stock-raising with subordinate farming, apparently must remain the dominant industries over large areas.

Life in Arid Plains

About $^1/_5$ of the land is desert because of insufficient rain. By no means all dry deserts are plains; some are plateaus, and within desert plains and desert plateaus there may be ranges of high hills and mountains (p. 504), though these, in most cases, receive more rain than their surroundings. Many of the conditions of life are similar in arid plains and plateaus, and they are considered together. Life in *cold deserts*, such as Greenland and parts of the Arctic plains (pp. 507–508), differs greatly from that in dry deserts. Only the latter are considered here.

The great deserts of the world occur in the zone of the trade-winds, or to leeward of high mountains. Their wide distribution and vast extent, the location of some of them near well-watered and thickly-settled regions, and the relations of their inhabitants to the latter, always have given them great importance in the life of the world. Save in the relatively small areas where irrigation can be practiced, or to which people may be attracted by valuable mineral deposits, deserts are doomed to have scanty populations.

The power of mineral deposits to bring people to deserts is illustrated strikingly in the case of Nevada. Although the deposits first discovered there occurred beneath strips of land only a few hundred feet in width and in a most uninviting desert, they attracted thousands of miners and prospectors, and made Nevada a state in five years. Virginia City had a population of some 11,000 in 1880, and was a place of much importance. Later, the population of the city and state declined greatly (p. 473), but in the last decade it has increased again (81,000 in 1910) due to new discoveries of ore. Butte, Montana, a city of 39,000 inhabitants, is supported largely by deposits of copper that underlie less than two square miles of arid land which, without the mines, could sustain only a few people.

Plant life in deserts. Plants require water for growth, and they lose water chiefly by evaporation from their leaves. It is clear that, in general, plants with unusual ability to get and store water, and plants which lose but little water, are best suited to deserts. Most desert plants are provided with many long roots, which enable them to get more moisture from the dry soil than would be possible otherwise, and at the same time help them to stand against the winds, often of great strength. The loss of water is reduced by such things as thick skins, corky bark, and coats of hair. Some desert plants have no leaves, and some have only a few small, rounded, and fleshy leaves. Thus the loss of water by evaporation from leaf surfaces is prevented or diminished. Many desert plants have

thorns, spines, and unpleasant or poisonous juices, which help to protect them against devouring animals. Scattered shrubs and coarse grasses are among the leading types of desert vegetation. Figs. 371 and 333 show desert plants of various kinds. The plants of deserts have comparatively little economic value at the present time.

After rain falls in the desert, many small, quick-growing plants spring up. Some of them bear bright flowers, and for a short time give the surface an appearance much in contrast with its customary barrenness. Soon they wither and die for lack of sufficient water.

Fig. 371. View in the desert near Tucson, Arizona. (W. L. Tower.)

The vegetation of oases (p. 504) is quite unlike that of the true desert.

Animal life in deserts. Like certain plants, some animals have developed characteristics which help them to live in the desert. The severity of desert conditions is shown, however, by the small number and the small variety of animals which can endure them. Like desert plants, desert animals are, as a rule, scattered. Some are very fleet of foot, and thus are able to move between widely-separated watering places and to escape from their enemies. Some are slow-moving, but most of these are venomous, and all of them are able to go without water for long periods. A desert is an impassable barrier to slow-moving animals which need water frequently. On account of the hot days and cool nights, many desert animals are more active during the night than during the day. Another characteristic of many desert animals is their dull color, not easily seen against the barren ground.

The camel is the most important animal of the arid regions of the Old World, having long been called "the ship of the desert" (Figs. 372 and 375). It is found in northern Africa and in Asia, from Arabia to China, and northward to northern Mongolia. A draft camel carries 300 to 600 pounds, according to size, the customary load being about ⅓ the weight of the animal. It is said that caravans sometimes travel 20 out of the 24 hours at a steady gait of 2½ to 3 miles an hour, halting only during the hottest part of the day.

The camel is an excellent example of adaptation to environment. It has great endurance with a small supply of food and water; small nostrils, which can be closed

Fig. 372. Part of a caravan in the desert.

so as to prevent the entrance of the finest wind-driven sand; eyes protected against sand and sun by extremely long, heavy lashes; and peculiar padded feet, fitted for the hot sands. The parts of the body subjected most to heat and friction are protected by great callosities. When at rest in an oasis, a camel drinks only enough for the time being, but when on the march it makes provision for many hours in advance. At the end of a long march, a camel has been known to drink as many as 20 gallons of water. During weeks of rest or light work, the hump increases in size; on long journeys, the material of the hump is absorbed into the system, maintaining the strength of the animal.

Human responses to desert conditions. Agriculture is impossible in deserts, without irrigation, and few places have sufficient water for that. Furthermore, grazing in many cases is possible only along the margins of the desert, or in oases. Since deserts afford

little in the way of food, they can support relatively few people, scattered widely in small groups. The conditions in deserts permit native tribes to make little progress in civilization.

Along the borders of many deserts the conditions of life are a continuation of those in semi-arid grasslands (p. 494). The people wander from place to place with their flocks and herds, the size of the social group being determined by the supply of water and grass. In general, the people are scattered even more widely than in the steppe, for the smaller amount of rain means poorer pasturage. Along the margins of certain deserts, the people sometimes do a little farming when the water supply permits, in order to supplement the often uncertain and always restricted living afforded by their animals. As a rule, pastoral nomads view tillage with contempt and dislike, and in some tribes which plant crops, the work is done by the women only.

We have seen (p. 500) that deserts may support considerable vegetation for a short time after rain falls. Along the edges of certain deserts, pasturage is available in the wet season, where the surface is bare in the dry season. This may control the seasonal migrations of pastoral tribes. In winter, the Arabs find scant pasturage for their goats and sheep on the northern border of the Sahara; in summer, they drive them to the slopes of the Atlas Mountains. In the same way, flocks and herds are driven at various points into the southern edge of the Sahara in summer, which is there the rainy season.

The arts of desert people are primitive and confined largely to household industries, for raw materials are few, and the wide dispersion of the people prevents much division of labor. Making leather and leather utensils from the skins of animals, pottery from clay, and blankets and rugs from wool furnished by the flocks, are typical industries.

Among American Indians, the potter's art was developed best in the arid Southwest. Here water was at a premium, and durable, water-tight vessels an absolute necessity. Perhaps the manner in which clay is hardened and baked by the desert sun when exposed by the evaporation of temporary pools of water, and along the courses of withering streams, gave the needed suggestion to the early inventor.

The Navajo Indians of the Southwest possess large flocks of sheep, and derive a considerable income from the sale of wool and blankets. The latter are made by the women in many artistic designs, and enjoy a wide reputation. It is said that the pastoral and industrial habits of the Navajos date from their theft of a flock of sheep from early Spanish settlers along the Rio Grande.

From force of necessity, most wandering desert tribes are robbers and marauders. They pillage caravans and hold travelers for

ransom, or exact heavy tolls in return for safe passage through the desert. They raid adjacent agricultural lands, and in some cases have levied regular tribute upon them, or have conquered and settled in them. The Sudan and Egypt have been invaded repeatedly by tribes from the Sahara. Where conquering people from the desert have adopted a sedentary life in more favored districts, they have sooner or later lost the warlike spirit and many of the other traits bred by the desert. This was illustrated by the Arabs (Moors) who settled in Spain, following their conquest of that country.

The inhabitants of deserts are excluded more or less completely from the culture of the outside world. Hence, as in mountains (p. 471), old manners and customs persist. Customs of the time of Christ still are observed by the inhabitants of the desert of Arabia. Scattered widely in small groups, desert people develop many dialects. They are compelled to eat very sparingly of the few things available. It is said that an ordinary European meal for one person would suffice for six desert Arabs. Nothing is wasted; the Tibbus of the Sahara eat even the skins and powdered bones of their dead animals. Their small food supply has led various tribes to check, in different ways, the growth of population. The scanty diet and severe hardships incident to life in the desert help to produce a distinct physical type. The men are prevailingly thin, but wiry, and capable of great exertion. Desert scenery is, in general, monotonous; therefore desert nomads have acquired unusual powers of observation and a remarkable sense of locality. Intellectual activity necessarily is restricted in the desert. The dull monotony of the environment and the lonely life tend to lead the mind into reverie and contemplation. The majesty of the larger deserts, their seemingly endless extent, their great dust and sand storms, and the precarious position of man, all tend to inspire feelings of awe and reverence. It is significant that Christianity and Mohammedanism were associated closely in their origin and development with the arid and semi-arid regions of the Old World.

Life in oases. In deserts, permanent settlements based on agriculture are possible only in oases, where there is water supplied by springs, artesian wells, or rivers. The source of the water supply may be outside the desert in well-watered regions, or within the desert where elevations rise high enough to compel the passing winds to give up a part of their moisture.

The Nejd Plateau, in the heart of Arabia, rises to an elevation of more than 5,000 feet, and here there are fertile oases, cultivated for centuries, and extensive pastures. Even in the Sahara, there are a few mountains which receive rainfall sufficient to support trees (Fig. 373). The streams formed on these mountain slopes disappear after descending to the surrounding desert. Some of the narrow valleys are farmed, and grazing is possible over larger areas. In order to encourage the settlement of wandering and troublesome tribes, the French have made many oases by sinking a great number of artesian wells in the northern Sahara, south of the Atlas Mountains. The water is obtained from sloping beds of porous rock which extend out beneath the desert from the mountains.

Fig. 373. The mountains of Tibesti, in the Sahara. Streams from the mountains wither and disappear in the surrounding desert.

Some oases serve merely as headquarters for tribes which roam over the surrounding desert in search of pasturage, and of caravans which they may attack. Some support towns, most of which are small. In general, the larger ones are located on the main caravan routes, where there is better opportunity for trade (p. 505). The houses in many cases are built of stone or adobe (sun-dried clay). In many cases, oases are cultivated most carefully in order to secure the largest possible returns from the restricted area which can be watered. Vegetables, cereals, and fruits, especially dates, are grown in the oases of the Sahara and the deserts of southwestern Asia.

The date palm has a trunk in some cases fifty to sixty feet in height, ending in a great crown of feathery leaves (Fig. 374). Bearing trees average from 100 to 200 pounds of dates a year, though yields of 500 or 600 pounds have been known. A tree may bear fruit for a century. The date palm is adjusted perfectly to conditions in the oases of low-latitude deserts, for it requires a very dry, hot climate, and a moist soil. It has been said with truth that the Arabs built their lives on the date palm. It was introduced into Spain by the Saracens, and brought by the Spaniards to Mexico and southern California, where it is an important decorative tree, but rarely bears fruit. In the future, it probably will have commercial value in the irrigated lands along the lower Colorado River (p. 373).

Oases in deserts are not in most cases such delightful gardens as often described, although in striking contrast with the barren desert about them. They are subject to frequent sand-storms, their water supply is small and in many cases impure, and their products are restricted in variety and in quantity. Nor are habitable oases numerous under natural conditions. The number of habitable places (in effect oases) in certain deserts has been increased by artesian wells (p. 504), the storage and diversion of stream waters, etc.

Fig. 374. Date palms loaded with fruit, Biskra, Algeria.

The oases of the Souf lie in the hollows among immense dunes in the Algerian Sahara. The date gardens of these oases are continually in danger of being buried by sand, for the air is in motion almost constantly, and even a gentle breeze starts clouds of fine sand. After every severe windstorm, the natives toil for days carrying the sand in baskets out of the gardens. In summer, when the temperature in the shade may reach 120° F., this work is done largely at night.

Commerce of the desert. Where a desert lies between well-watered and populous regions, important trade may be carried on across it. Some trade is carried on also between agricultural lands and the borders of neighboring deserts, because of their contrasted resources and the desire of the desert people to supplement their meager products. Timbuctoo, on the Niger River, and Damascus, in Syria, are examples of places which serve as gateways

to deserts. The former is said to be visited each year by 50,000 to 60,000 camels. One of the few occupations of the desert is that of driving camels and leading caravans. Mohammed himself was a caravan leader.

For centuries, goods were carried in large quantities across the vast deserts of central and western Asia only by pack animals, especially the camel, and even to-day this is the case over most of the region (Fig. 375). A number of caravan routes cross the Sahara, extending from oasis to oasis. The trade which originates or terminates in the Sahara is largely in dates, salt, clothing, cereals, and camels, while for centuries

Fig. 375. Camels in northwestern India. A portion of a caravan which has come through Khyber Pass from Afganistan.

the through trade has included such things as ivory, gums, spices, and gold dust. Prince Henry of Portugal learned of the trans-Saharan trade while on an expedition against the Moors in northern Africa in 1415, and partly with the idea of diverting the trade of the Guinea Coast to his own country by water, he began the long series of explorations along the coast of Africa which culminated in the discovery of the all-water route to India. The use of the latter route to the East injured greatly the caravan trade across Asia. A trans-Saharan railroad is now projected.

Political conditions in deserts. The hard conditions of life in deserts repeatedly have driven their inhabitants out to conquer other regions (p. 503). On the other hand, the conquest of deserts from without always has been attended by great difficulties, and in some cases never has been accomplished. The love of freedom and the fighting ability characteristic of desert peoples, in addition to the difficulties which an invading army finds in the lack of roads, water, and food, have helped to produce this result. Furthermore, the scant resources of deserts have made them relatively uninviting to outside people.

The great body of the people of Arabia and of the Sahara are still free. France has undertaken the control of the latter to secure safe communication between her possessions to the north and south of the desert.

Life in Arctic Plains

The plains which border the Arctic Ocean are known as *barren lands* in North America, and as *tundras* in Eurasia. They form a *cold desert*, snow-covered for some two-thirds of the year. The short summers, low temperatures, and cold or frozen soil prevent agriculture, and restrict vegetation chiefly to stunted bushes, mosses, and various quick-growing, flowering plants. The few, widely scattered inhabitants of the tundras depend largely on their herds of reindeer and on hunting for their living. Fishing is an important occupation during the three or four months when the streams are free from ice. A nomadic life results from the necessity of following the game and the reindeer herds, which wander half-free in search of pasturage. As in the steppes and dry deserts, this nomadic life means small, easily transported dwellings — in many cases a tent consisting of a framework of poles covered with skins — and few and simple household utensils. Some of the tribes move northward with their herds in the summer, and return to pass the winter in the forests which border the tundras on the south. Here the timber affords some shelter, fodder is available for the reindeer, and game may be hunted for food and fur.

All that the camel is to the inhabitants of low-latitude deserts, the reindeer is to the men of the Arctic desert. It is indifferent to cold, lives on *reindeer moss*, is an excellent draft animal (Fig. 376), and its milk constitutes an important item of food. Its flesh is used for food; its bones and horns afford material for making various implements; its tendons and sinews serve for thread; and its skin is used for shelter and clothing. The reindeer is the most desirable form of wealth on the tundra. In some places, a herd of 50 head, which will support one family of four or five members, requires between 4 and 5 square miles of tundra pasturage. This means at best a very sparse population.

Some years ago the United States Government imported nearly 1,300 reindeer from Siberia, for the benefit of the natives of northern Alaska. The herds have increased rapidly, and are proving of great value.

The Athapascan Indians of the Arctic Coastal Plain of Canada are among the most primitive of their race. They lead a precarious and difficult existence, depending of necessity on hunting and fishing.

The cold of the Arctic plains permits little progress. Life is a constant struggle to secure food, clothing, and shelter. There is little opportunity for trade. Situated upon the outskirts of the inhabited world, the frozen deserts of the north have played a much less important part in history than the centrally-located deserts of lower latitudes. Nor does it seem likely that they can become of much importance in the future.

Fig. 376. Reindeer and sledge.

Life in Humid Plains of Low Latitudes

Near the equator, the climate of the lowlands is characterized by heavy and frequent rains, and by high, nearly uniform temperatures throughout the year (p. 160). As we have seen, this results in a dense, varied vegetation (Figs. 377 and 378), such as that constituting the forests of the Amazon and Congo valleys. The distinctive life of humid plains in low latitudes is therefore that of the tropical forest, or jungle. In some of the other realms which we have considered, man has been handicapped by lack of useful vegetation. Here, the very abundance of plant life is an obstacle to progress.

Response of natives to conditions in tropical forests. The dense forests of equatorial regions are occupied by relatively sparse populations of backward natives. The high temperatures and the moisture are enervating, and continued exertion is difficult. The climate has encouraged indolence and shiftlessness until they

have become leading characteristics of the natives. The luxuriance of the natural vegetation makes the clearing of land difficult, and even where it is cleared, a constant struggle is necessary to keep back the encroaching plants. Unused trails through the forest are obliterated quickly, and all trace of settlement soon disappears from abandoned clearings. Under these conditions, it is not strange

Fig. 377. Tropical forest and river in flood. Southern Mexico. (W. L. Tower.)

that agriculture rarely is practiced. An indolent people will not undertake hard work when this is unnecessary. Throughout the world, man appears to have developed agriculture, or to have domesticated animals, generally only when the natural food supply became too small. In the equatorial forest, there is an abundant natural food supply. The natives live chiefly on the fish afforded by the many rivers, and such game as inhabits the forest. This is supplemented in many places by the products of certain plants, such as the sago palm.

The large animals found in many places in the open country adjacent to the tropical forests penetrate the latter only a short distance. They come and go

through the denser growth by paths which they keep open by frequent passing (Fig. 378). Well within the forest, there are few sources of food for animals near the ground. Flowers and fruits are found in the tree tops, however, and hence animal life is represented chiefly by flying and climbing forms, such as insects,

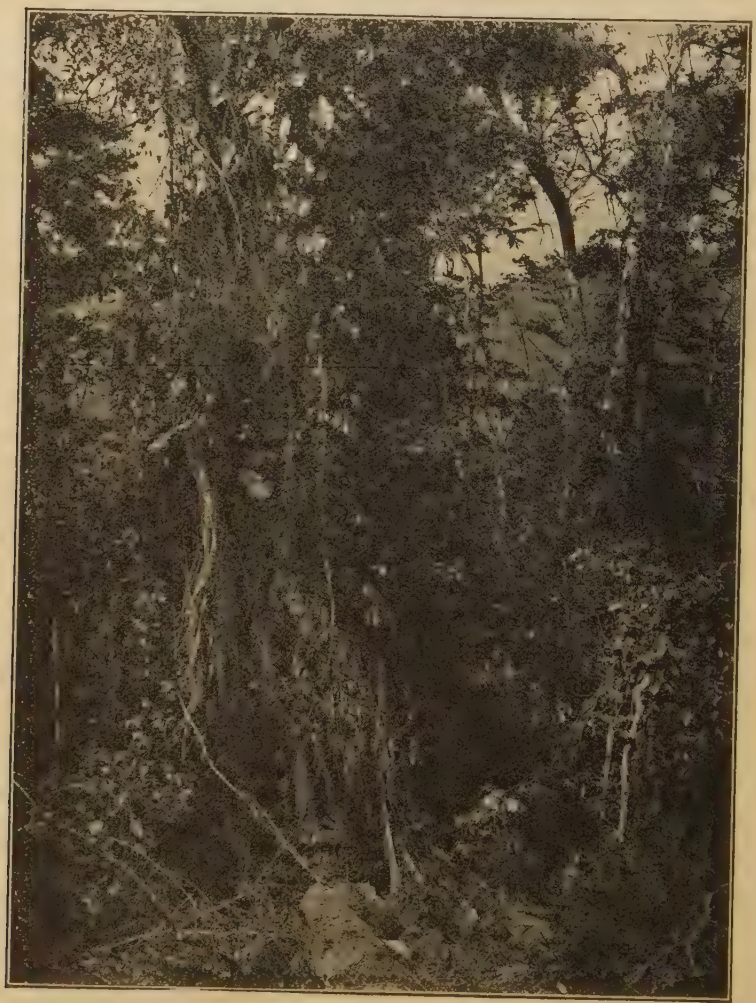

Fig. 378. View showing plants of various kinds in a tropical forest. Path through the forest shows at the right. Southern Mexico. (W. L. Tower.)

birds, snakes, and monkeys. Many of the birds and snakes resemble the foliage in color, a fact which favors concealment.

Little is needed by the inhabitants of the tropical forest in the way of clothing and shelter. Some of the lowest savages have no homes. Some of the people live in floating houses on the rivers, which constitute the most important lines of travel through the forest, or in huts built on piles, in order to escape the floods.

Agriculture has been developed in a small way in clearings near the edges of the equatorial forests. In some cases, this consists in

Fig. 379. Pygmy village in the Congo forest.

scarcely more than planting crops, and leaving them to grow. Bananas, bread fruit, rice, and other things are grown in different places, chiefly by the women. Very little labor brings large returns, and thus steady effort is discouraged. As in the equatorial forest generally, life is too easy; there is no spur to progress.

The Pygmies who inhabit parts of the Congo forest represent perhaps the lowest type of human beings. The average height of the adults is said to be only a little more than 4 feet, and many are shorter. They make no attempt at farming, but live by hunting and fishing. They kill small game with arrows and spears tipped with a poison made from certain plants, and capture even large animals in covered pitfalls which they construct in the narrow runways followed by the animals (p. 509). They catch fish in nets or baskets, sometimes stupefying them by putting in the water the powdered fruit of a palm. They live in small, scattered groups where there are openings in the undergrowth (Fig. 379), building tempo-

rary huts consisting in many cases of flexible sticks covered with leaves, and shifting from spot to spot in quest of game. They carry on some trade with other tribes, bartering meat, skins, and plant poisons, for weapons and vegetable food. The Pygmies have no arts save those noted in connection with their hunting and fishing; no family ties; no traditions of their ancestors; and, it is believed, no idea of a future state.

Commerce of tropical forests. The forests of tropical lowlands furnish products of much importance to the outside world, such as ebony, mahogany, rubber, gums, palm-oil, and copra. Trade follows the waterways, and in general those sections are most favored commercially which are situated conveniently with reference to a navigable river (p. 165).

The humid lowlands of the tropics are of far greater importance to man than the Arctic plains, but unfortunately the settlement and development of them by people from middle latitudes are attended with great difficulty (pp. 157–158).

Questions

1. (1) How might one prove that a given coastal plain was formerly a marginal sea-bottom? (2) How might one determine whether such a plain became land by rise from beneath the sea, or by lowering of the surface of the sea?

2. By what are the characteristics (topography, fertility, etc.) of any given plain determined?

3. Why are the soils of most plains thicker and more fertile than those of plateaus and mountains?

4. (1) What great plains, now of little value to man, are likely to have greatly increased importance in the future? Why? (2) What ones are likely to continue of little significance? Why?

5. What are the principal factors which influence the value of semi-arid land for "dry-farming"?

6. Compare and contrast the life of primitive peoples in arid deserts and rugged mountains.

7. How does the life of people in Arctic regions resemble that of desert tribes in lower latitudes?

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CHAPTER XIX

COAST-LINES AND HARBORS

Importance of coast-lines. There is great freedom of movement over the ocean. A ship may sail direct from one port to another thousands of miles away (Fig. 113), or it may make a roundabout voyage, calling at intermediate ports on the way. A modern steamship can carry ten to twenty train loads of freight in a single cargo, and it costs far less to operate one steamer than to run ten or twenty trains. Furthermore, trains call for the maintenance of a railway, which is very expensive. Hence the carriage of freight by rail is much more expensive than by boat. The cheapness of ocean transportation makes it possible to carry enormous quantities of relatively low-priced freight, such as cereals, lumber, and raw materials of all sorts, from one part of the world to another. Modern commerce, therefore, depends much on the ocean highway (Figs. 114 and 115), but it owes its rapid development in part to favorable coast-lines through which access to the sea is secured.

The prosperity of some countries depends largely on commerce. Holland, for example, at the mouth of the Rhine, is situated favorably for sea trade, and through its commercial activities Dutch influence has been extended to many parts of the earth. Countries like Bolivia and Switzerland, shut off from the sea, have been more limited in their influence. Countries with an unfavorable sea-coast, like Austria, or with but small extent of coast-line, like China, are handicapped when compared with a country like the United States, with fairly good coasts on three sides.

Successful commercial voyages from one continent to another require skill in navigation. In early days, seamanship was much influenced by the character of the coast-line. It was unsafe to venture far from land, for vessels were small and there was no way of determining position accurately, or of reckoning distances. Hence seamanship developed first along the shores of quiet inland seas like the Mediterranean, or where deep bays and sheltering islands

invited ventures from one headland or island to another, as in Norway. Thus the first nations to become sailors, fishermen, explorers, and sea traders were influenced by the nature of their sea-coasts.

With modern steamships and a highly developed science of navigation, voyages are undertaken readily to distant parts of the earth. But even the giant steamship needs safe anchorage in quiet waters while its cargo is being received or discharged. In some cases, ocean commerce is carried on from places which have no

Fig. 380. Map showing regular outline of newly elevated coast. Dotted lines indicate contours; interval 25 feet. (Nome, Alaska, Special Sheet, U. S. Geol. Surv.)

harbor. In such cases, vessels anchor off shore while the cargo is carried (lightered) from them to shore, or from shore to them, in small boats. During heavy seas lightering is impossible, and many wares cannot be handled to advantage in this way at any time. Hence, other things being favorable, coast-lines with deep bays and good harbors are natural centers of seafaring activities, as in early days.

Characteristics of coast-lines and their origin. If land along a coast were to be elevated or the sea-level lowered, a portion of the sea floor would be exposed. The sea floor is generally smooth and even. Hence the emergence of a coastal strip tends to produce an even, regular shore-line (Fig. 380) fronted by shallow water. Coasts which have risen recently, relative to sea-level, are without good harbors, except where some large river, flowing across the coastal plain, offers a haven at its mouth.

Commerce with such a coast is handicapped severely. Large vessels must anchor off shore while their cargoes are lightered, unless artificial harbors have been provided by the construction of breakwaters, jetties, or long quays. The east coast of India, most of the Gulf coast of Mexico, and much of the west coast of South America present these conditions. Madras and Vera Cruz have artificial harbors, because the demand for a commercial outlet from an important region justified the great expense involved in making a harbor. The coasts of most tropical lands are more regular than those of higher latitudes, and this has helped to retard the development of tropical regions.

The submergence of a coast land having hills and valleys produces a new shore-line which is irregular (Fig. 381). The drowned valley bottoms form bays, while the inter-valley ridges stand forth as headlands. Isolated hills on the old lowlands may front the new coast as islands. Such a coast-line commonly has many sheltered bays and harbors. Deep water is likely to be found over the submerged river channels, and may extend many miles up the drowned valleys, making it possible for vessels of moderate draft to go far inland. Thus the drowned lower portion of the Hudson has a minimum depth of 11 feet for more than 150 miles.

Commerce is favored by the irregular coast of a newly sunken land area. Most important commercial ports, such as the Atlantic ports of North America and Europe, are along depressed coasts. The chief sea fisheries, also, are associated with irregular coasts, partly because of the many convenient refuges for fishing fleets. Not infrequently, also, large bays, like Chesapeake Bay, support valuable shore fisheries. In some places, as along parts of the Atlantic coast from Chesapeake Bay to Maine, irregular coasts afford more good harbors than commerce needs, and many of them are used only by small fishing fleets.

Where an irregular coast-line is produced by the sinking of a coastal plain, the bays may be wide (Why?), like Delaware and Chesapeake bays, but most of them are shallow, except along the line of the old river channel, and they may have marshy land along their borders. Few places on the shores of such bays are suitable for the development of a great port. Where a higher, more rugged region is submerged, the bays are likely to be narrow and fiord-like, as in Alaska and Norway. Most of them are deep, and some are bordered by high land which rises so abruptly from the water

that no room is available for a city. Where the ocean finds access to an interior valley, a long inland arm of the sea, like Puget Sound, is developed. The sheltered inner route from Puget Sound to Alaska is perhaps similar to Puget Sound in origin. A former mountain pass in the Coast Range, now submerged, forms the picturesque Golden Gate entrance to San Francisco harbor (Fig. 382), and a

Fig. 381. Map showing irregular outline of a depressed coast. Dotted lines indicate contours; interval 20 feet. (Monhegan, Maine, Sheet, U. S. Geol. Surv.)

little further sinking would change much of the central valley of California into a great sound.

The modification of shore-lines. All shore-lines are subject to constant changes by waves, shore and tidal currents, rivers, winds, and ice.

The effect of glaciers on shore-lines has been noted (pp. 393, 398). Parts of the coast of New England have been modified in this way. Much of the value of Boston harbor depends on the protection afforded by islands of glacial origin. Shore ice has little effect on coast-lines, but is a serious obstacle to navigation along some coasts (p. 381).

Winds often make dunes on the sea shore (p. 314), and the dunes may afford the land some protection from the sea, as along the coast of Holland, but they rarely change the outline of the land to any great extent. The action of the wind in producing waves and currents is much more important.

Rivers affect shore-lines but little through erosion, but delta-building rivers may change the outline of the land greatly (p. 374).

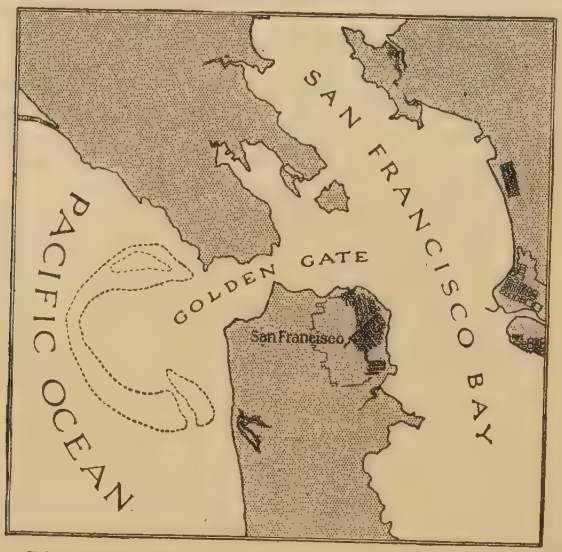

Fig. 382. Diagram showing arm of ocean formed by invasion of valley through a submerged sag in mountain range. San Francisco harbor. Dotted lines indicate bar across entrance. (U. S. Coast and Geod. Surv., Chart No. 5500.)

Other things equal, delta lands grow most rapidly in the quiet waters of inland seas and bays. Thus the delta of the Mississippi (Fig. 259) extends into the Gulf as a great irregularity, with many smaller irregularities about its borders. Delta-building in bays may lessen the irregularities of the coast, by filling the indentations. Thus most bays entered by large streams are made shallower constantly by the deposition of river sediments. The value of Mobile Bay is lessened in this way, and many others, especially about the Mediterranean, which were important centuries ago, are now partly or entirely filled. The city of Adria, Italy, once the port for the mouth

of the Po, is now fourteen miles from the coast, and the Rhone delta, building forward at the rate of 200 feet a year, has changed the coast-line so rapidly that it has never developed an important port (p. 415).

On exposed coasts, delta-building is less rapid (Why?), and produces fewer irregularities than in partially enclosed waters. The delta of the Amazon, for example, does not project beyond the general coast-line. Delta lands are low, marshy, and subject to floods, while the indentations of their borders are shallow, and, in most cases, subject to deposition. For these reasons, they are poorly suited to the development of ports, and except at the mouths of great rivers, like the Mississippi and Amazon, deltas rarely become the sites of important commercial centers.

Fig. 383. Wave erosion of an exposed headland.

Waves and currents are the chief agents which modify coast-lines. On irregular coasts, the general tendency of waves is to wear away headlands (Fig. 383) and fill bays, thus making the shore more regular. On regular coasts, their general tendency is to wear back the shore-line. Waves and currents therefore tend to destroy harbors. In many cases serious interference with commerce is prevented only through costly operations in the protection and improvement of harbors.

Waves are at work almost constantly on some part of every coast-line. Large waves are more powerful than small ones; hence wave work is influenced largely by the winds. Coasts exposed to stormy seas are affected more than those in quiet waters, and those of loose material, such as gravel and sand, are attacked more effective-

ly than those of solid rock. Along the eastern coast of the United States, the unconsolidated sediments of the coastal plain, and the glacial drift of parts of New England, permit more rapid changes than are possible on a rocky coast, like that of Maine or Norway.

Wave action varies according to the nature of the coast and the depth of water. In deep water away from shore, the water in a wave does not move forward. An idea of its motion may be gained from a field of waving grain, where wave after wave crosses the field, though each moving stem is fixed to the ground. Again, if one end of a long piece of rope is fixed, while the other end is shaken up and down, successive waves travel from the end shaken to the

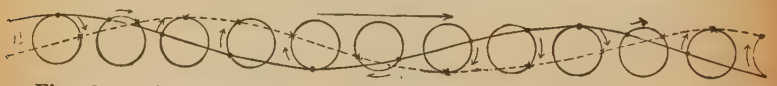

Fig. 384. Diagram to illustrate the movement of water in waves. The small circles represent the movement of water particles.

end which is fixed. Both the grain and the rope come to rest finally just where they started. The curved line of Fig. 384 represents the crest and trough of a wave (the undulating ocean surface) where the water is deep, while the circles show the path of a particle of water in the wave. The motion of the water in a wave is greatest at the surface, and diminishes rapidly downward. For this reason, waves have little or no effect on the ocean-bottom in deep water.

When a wave advances into shallow water, its motion changes, for the movement of the water in the lower part of the wave is hindered by friction against the bottom. The top tends to pitch forward, making *surf* (Fig. 385). A somewhat similar effect may be produced in deep water, when winds blow forward the tops of waves, forming *whitecaps*. Hence during storms, and especially in shallow water, there may be a distinct forward movement of the water in a wave. But generally in deep water it is only the wave motion, not the water, which travels forward. If the water moved forward with the wave, the ocean would be hardly navigable, for in many cases the forward motion of the wave is as fast as the forward motion of a steamer.

In shallow water, the water which is thrown forward against the shore runs back down the slope of the bottom as the *undertow*, so dangerous to bathers on many coasts. Drownings have resulted so frequently from bathers being caught by the undertow that many

bathing beaches now have regular life guards constantly on watch during the bathing hours. This forward and backward movement of the water is able to effect much erosion, if the movement is vigorous and the waves are well supplied with tools.

If waves reach the shore obliquely, they produce a movement of water parallel to it. Such a movement is known as a *shore* or *littoral current.* Where a shore is exposed to prevailing winds

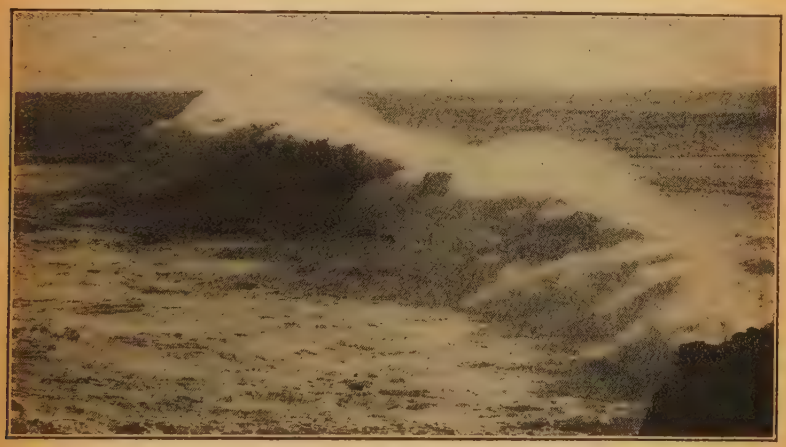

Fig. 385. Surf wave at Point Buchon, California.

from one quarter, the resulting shore currents are constant in direction. Littoral currents are most important in moving the material worn from the land by waves.

Erosion by waves. The force of waves hurled against the shore may be very great. Surf has been thrown to heights of more than 100 feet with force enough to destroy lighthouses. The strength of waves on the coast of Great Britain is sometimes as much as three tons per square foot, and the average for winter waves is said to be about one ton per square foot. Such waves are able to move masses of rock weighing several tons. During one storm more than 200 blocks of concrete, weighing 4 tons each, were swept from the breakwater at Cherbourg, France, and tossed over an embankment. It is clear, therefore, that the force of waves is great enough to wear shores, even of solid rock. Where deep water is found near shore, as along most precipitous coasts, erosion depends on the work of

the water alone. Where waves break in shallow water, pieces of rock may be hurled forward with the rushing water, and serve as powerful tools to cut away exposed cliffs. In severe storms, cliffs are, in rare cases, driven back many feet in a few hours. The waves of lakes are never so strong as the great waves of the sea (Why?), but the storm waves of large lakes have great force, and sometimes wash away piers and breakwaters, even in a single storm.

Fig. 386. Cliff showing undercutting by waves; Kelleys Island, Lake Erie. (H. E. Wilson.)

The existence of so great a force as that of waves on an exposed coast has led to many attempts in different countries to use wave power for practical purposes. None of the devices yet tried has proved practicable on an important scale. A chief obstacle is the extremely variable character of the waves.

Where waves erode the land they make steep slopes, or *cliffs*. As waves cut away the base of a cliff (Fig. 386), the upper part may slump. In this way the cliff recedes more rapidly, and more material is supplied for the waves to hurl against the cliff base.

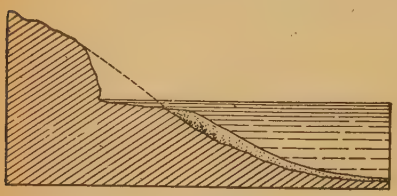

Fig. 387. A cliff fronted by a terrace. Outer (dotted) part of terrace built by deposition of sediment; inner part due to wave cutting.

Cliffs developed by wave-cutting are bordered by *wave-cut terraces* a little below the surface of the water (Fig. 387). The width of such a terrace measures roughly the advance of the water on the land by the cutting of its waves. By rise of the land, or by sinking of the sea, the terrace may become land (Fig. 388).

By driving back sea cliffs, waves tend to increase the ocean area at the expense of the land. The island of Heligoland, off the German

coast, has been reduced by wave action to less than one-twentieth of its area a thousand years ago. Numerous shoal areas off the New England coast are due to the complete removal of small islands. Where land near the coast is high, a well-developed cliff may interfere with communication between the sea and the interior. Where the coast land is low, sea cliffs are unimportant (Fig. 389).

Fig. 388. Wave-cut terraces now well above the sea, indicating relative change in level of land and sea. Seward Peninsula, Alaska.

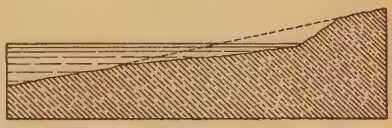

Fig. 389. Diagram to represent a low sea cliff.

Deposition by waves and shore currents. Material worn from the land by waves, or brought to the shore by rivers, is shifted about by waves, undertow, and shore currents, but finally comes to rest. If left at the shore-line it makes a *beach* (Fig. 390). If carried farther out into the water, it takes on other forms. Fine particles of mud generally are carried out into deeper water, while coarser material, such as sand and gravel, make the beach.

Fig. 390. Wave-cut cliff with some of the material left in the form of a beach. Lake Michigan.

Waves may build *reefs* or *barriers* a little out from the shore. They are developed near the line of breakers, where the incoming wave leaves much of the sediment which it is moving toward the shore. The undertow may contribute sediment to the reef by carrying it out

from the shore. There are several such reefs along some coasts, parallel to one another and to the shore. They are, in some cases, troublesome to navigation, especially where they make shallow water, or "a bar," at the entrance to a harbor.

Fig. 391. Diagram representing a cross-section of a barrier beach.

Waves may build the crest of a reef above water, converting it into land (Fig. 391). By building dunes, the wind may then aid in raising the surface still higher above the water-level. This seems to have been the origin of many low, narrow belts of sandy land parallel to coasts, with marshes and lagoons behind them (Fig. 392). Such barriers are formed only in shallow water. They are common off low coastal lands, for off most such coasts the water is shallow. This type of shore is illustrated at many places from New York to Texas. The coast-line produced by the reefs is more regular (as a rule) than that of the mainland behind them. Lagoons enclosed behind reefs provide harbors in some places where otherwise they would be lacking. In time, wave action may cause such coast-lines to recede even beyond the original line of the mainland.

Fig. 392. A curved barrier beach enclosing a lagoon; Gilbert Lake, near Brainerd, Minn.

Where a shore current reaches a bay, it does not, as a rule, follow the outline of the bay, but tends to cross it in the direction in which it was previously moving. Under such circumstances it may build an embankment or *spit* of gravel and sand near the entrance to the bay. Currents do not build spits above the water, but waves may build them up into land by washing material from their slopes up to their tops. After they become land, the wind may build dunes upon them (Fig. 395). When spits (Fig. 393) cross bays they become

bars. Along some coasts, as on the south side of Martha's Vineyard Island, such bars have closed the entrances to many bays.

Reefs, spits, and the land to which they give rise, increase the irregularity of the coast-line for a time; but they represent the first step toward regularity, for, after the reefs have become land, the lagoons behind them are likely to be filled with sediment washed down from the land or blown in by the wind (Fig. 394).

Deposits of gravel and sand are sometimes made between a mainland and islands near it. Nahant Island, on the coast of Massachusetts, and the Rock of Gibraltar, on the coast of Spain, have been thus "tied" to the mainland.

Bars and reefs often hinder the movements of vessels, especially when they tend to close the entrances of harbors. A spit which does not obstruct the entrance to a harbor is sometimes an advantage, since it breaks the force of incoming waves. Spits which form harbors have determined the location of numerous villages and cities. The harbor of Plymouth, Mass., for example, is protected by a spit which makes a natural breakwater (Fig. 393). Provincetown, Mass., and Erie, Penn. (Fig. 395), have harbors made by curved spits.

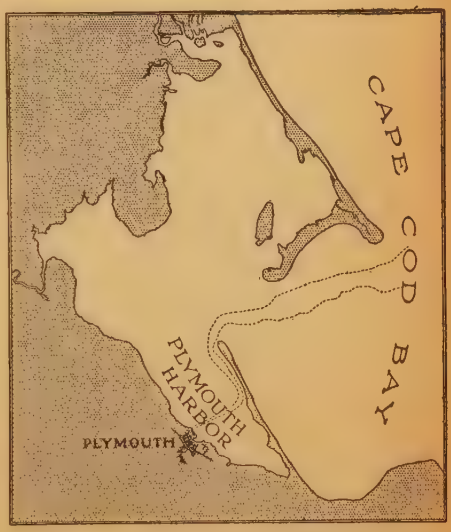

Fig. 393. Map of harbor formed by spits; Plymouth, Mass. Broken lines indicate approximate limits of channel. (U. S. Coast and Geod. Surv., Chart No. 110.)

Harbors. Harbors vary greatly in value. A good harbor must, first of all, afford shelter from stormy seas, must be deep enough for large vessels, must be connected with the open ocean by a deep channel, and must provide room for the anchorage of many ships. The direction whence the storm waves come and the direction which the harbor entrance faces have much to do with its safety. A harbor

with a wide, unprotected entrance, facing the south, may be a good haven on a coast where the storm waves come from the east or northeast. The harbor of Gloucester (Mass.) illustrates this

Fig. 394. A barrier beach with marshy tract (filled lagoon) behind it. Lasells Island, Penobscot Bay, Me.

condition. The straighter and wider the channel leading into the harbor, the better, for long vessels cannot navigate safely a narrow, winding channel. This fact alone made it necessary to open a new entrance (Ambrose channel) to New York harbor. The water near the shore should be deep enough to permit vessels to reach the docks, and the shore should be suitable for landings and port facilities. There also should be freedom from ice.

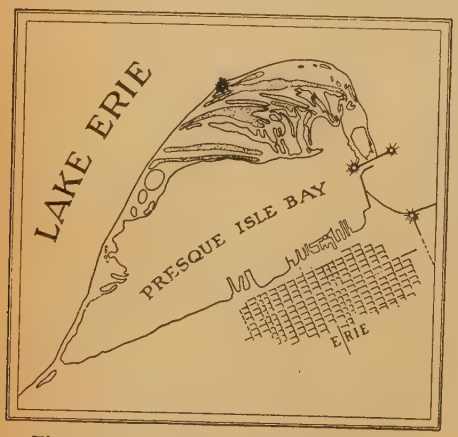

Fig. 395. Map of harbor formed by curved spit; Erie, Penn. Dotted areas are lines of sand dunes. (Erie, Penn., Sheet, U. S. Geol. Surv.)

A harbor may possess all these qualifications and yet be of little value commercially. Thus Casco Bay, Maine, is said to be one of the finest havens in the world, but Portland is one of the lesser Atlantic ports. For commercial importance (Figs. 396 and 397), a harbor must have convenient internal routes either to a large producing region, or to one which requires many wares from the outside world. Thus New York has surpassed all other Atlantic ports, not

Fig. 396. Diagram showing movement of exports from the United States by coasts and leading ports, 1910. Values are expressed in millions of dollars. Percentages refer to proportion of total trade.

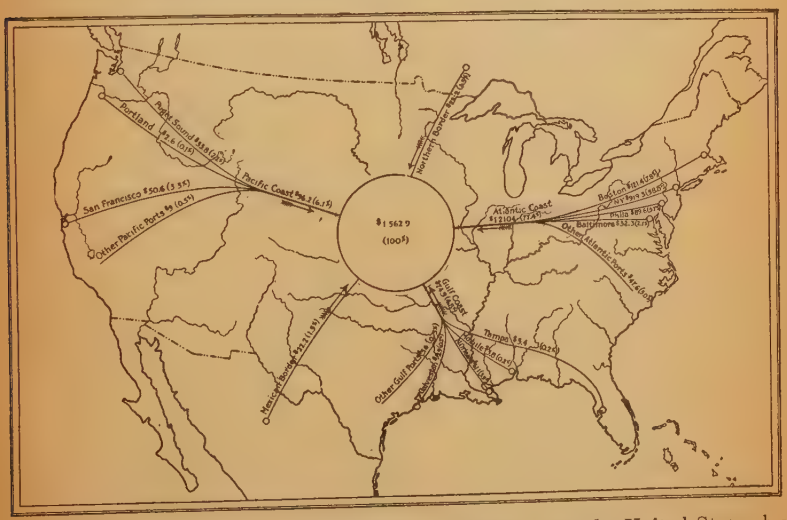

Fig. 397. Diagram showing movement of imports into the United States by coasts and leading ports, 1910. Values are expressed in millions of dollars. Percentages refer to proportion of total trade.

because of superior harbor facilities, but largely because of its better connections with the interior, where many articles of commerce are produced and consumed.

Harbors at the mouths of large rivers are likely to have easy communication with the interior through river navigation, and the valleys are natural routes for railways. Thus important ports, like New Orleans (Figs. 396 and 397), Pará, Calcutta, and Rangoon, are near the mouths of rivers which serve as highways of trade.

Such river-mouth harbors, however, have many disadvantages. The current is a handicap for sailing vessels, which are still important

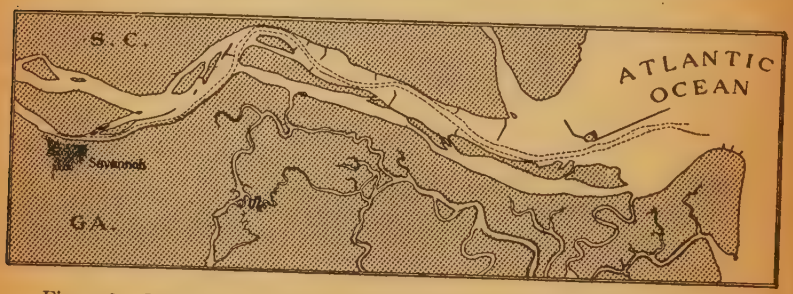

Fig. 398. Map of a river-mouth harbor; Savannah, Ga. Broken lines represent the approximate course of the channel; solid lines in the river indicate jetties to control currents. (U. S. Coast and Geod. Surv., Chart No. 156.)

in coastwise commerce. Most large rivers, like the Mississippi, Amazon, and Ganges, have built large deltas, on which the stream breaks up into distributaries. These mouths may be blocked by deposits of silt and mud. Shallow water is common near the entrances, and this disadvantage increases as larger vessels are built. Not infrequently the main discharge of the stream shifts from one mouth to another. In many rivers winding channels are kept open only by building jetties (Fig. 398).

For these reasons expensive operations have been undertaken in some cases, such as the building of the Eads jetties at the Southwest Pass from the Mississippi, in order to keep one mouth open and deep at all times. In other cases, the port developing in connection with a river has been located at the nearest favorable place, free from the disadvantages of the river mouth. Thus Marseilles is about 30 miles from the mouth of the Rhone, and Kurachi

is some 15 miles from the mouth of the Indus. In each case, connection with the river, inland, is made by rail.

At Pará, Brazil, great engineering works are necessary to facilitate and cheapen the handling of the heavy traffic of the Amazon Basin. Pará, 65 miles from the ocean, is located near the only good entrance to the Amazon, but in this broad mouth the water for a mile or two from shore is too shallow for large ocean steamships. To lighter most of the cargoes, valued at more than $50,000,000 annually, meant much added labor and expense in handling. This handicap is to be overcome by building a long quay out in the stream, and filling in between the quay and the shore with the material dredged out of the basin in front of the quay. In this way, a depth of over 30 feet at the quay wall will be obtained.

Along recently elevated coasts, the mouths of large rivers commonly offer the only natural havens. River-mouth ports are also more common in tropical countries than elsewhere, because the people of these regions depend largely on waterways for internal communication (pp. 165, 512).

Most of the important harbors of the world have been produced by the submergence of river valleys. The harbors of New York, Philadelphia, San Francisco, Seattle, Buenos Aires, London, Hamburg, Shanghai, and hundreds of others belong to this class. The embayed river has many advantages over such a river as the Amazon, as the place for a commercial center. The entrance rarely shifts, is likely to be deep, and not infrequently tidal currents prevent its being filled by sediment. In many cases, also, the borders of the land are less likely to be low and swampy, and therefore are better suited for the development of a port. Water navigation may also be possible for some distance inland. Thus river craft can go from Shanghai far into the interior of China, and Hamburg benefits from a water route which reaches the Austrian frontier.

Many harbors on embayed coasts are affected by the deposition of sediment in or across their entrances (Fig. 399). The direction in which the entrance opens, with respect to the movement of shore currents, is an important factor affecting the value of the harbor. Thus the embayed mouth of the Housatonic River receives the material drifted westward by the shore currents of Long Island Sound. As a result its entrance is very shallow, and the river mouth is not the site of an important port. New Haven harbor, on the other hand, is so situated that the shore current is turned away

from the entrance toward deeper water. Its entrance has a depth sufficient for the passage of good-sized vessels, and partly for this reason New Haven early became an important shipping center. These examples show that the relation of a harbor to shore currents may be such as to counteract the advantages of favorable communication with the interior. On some coasts where harbors occur only at rather long intervals, jetties have been constructed to overcome the action of shore currents (Fig. 400). Galveston harbor has been improved in this way.

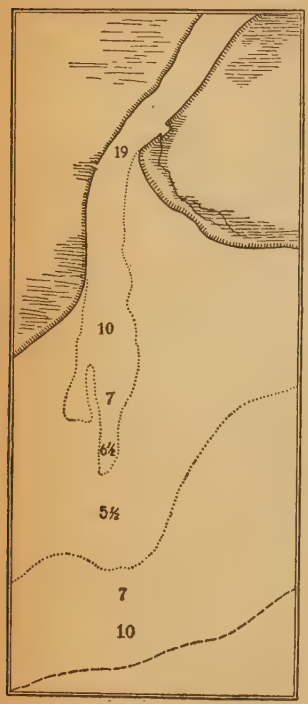

Fig. 399. Map of river mouth with shallow water over the bar at the entrance; Calcasieu Pass, La. Dotted lines indicate 6 foot depth. Broken line indicates 12 foot depth. Figures give depth in feet. The channel across the bar changes with every gale, so that strangers are warned not to enter without a pilot. (U. S. Coast and Geod. Surv., Chart No. 202.)

Fiords are numerous along some coasts, but they are relatively unimportant as sites for large ports. This is due partly to the location of many fiords in high latitudes where large commercial activities are less common, and partly to the character of the fiords themselves. Many are too deep for anchorage in the main channel, their land borders are too precipitous for the growth of a large port, and they are associated in many cases with the flanks of mountains which hamper communication with the interior (Fig. 281).

The quiet upper waters of long fiords, however, afford good protection from storm waves, and every primitive people occupying a fiord coast early developed the sea-going habit. The configuration of certain fiord coasts may be taken advantage of in the future to develop power from the tides (Fig. 281).

Lagoon harbors may be produced by the formation of barriers, or by the growth of coral reefs. The former are numerous along the Atlantic and Gulf coastal plains, but, except where combined with depressed coast-lines, few attain commercial value. Lagoon harbors formed

by barriers have many disadvantages. The water off shore is rarely deep, the inlets are commonly narrow and shallow, and many have such strong tidal currents as to prevent the ready passage of small craft. The inlets also may be closed by sediments deposited by waves and currents, unless protected by artificial works. The lagoon, even if deep originally, or dredged to satisfactory depths, tends to become shallower through the deposition of (1) river sediments, (2) material blown or washed from the bar, and (3) by the growth of vegetation in it.

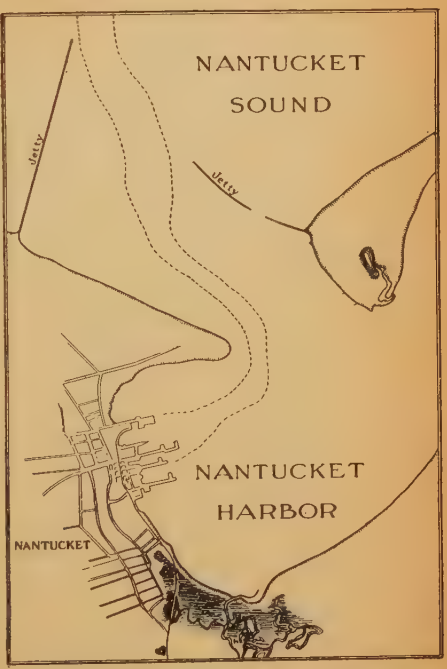

Fig. 400. Map of harbor maintained by jetties; Nantucket, Mass. Broken lines indicate approximate course of channel. (U. S. Coast and Geod. Surv., Chart No. 111.)

Most lands bordering lagoons are low and marshy on the mainland side, with only a low, sandy island, exposed to winds and waves, on the ocean side. Neither is well fitted to be the site of a great port. Galveston is the best example of a port with a lagoon harbor; large sums have been spent to develop and maintain both the harbor and the city.

Lagoon harbors due to coral reefs or atolls are fairly numerous in tropical waters, especially in the South Pacific. Such harbors are of little commercial importance, because most of them are associated with small islands, which have few people, and produce little. The Great Barrier Reef of Australia is a handicap rather than a benefit to the commerce of that country.

The chief disadvantages of spit harbors (Figs. 393 and 395) result from the continued growth of the spit, the frequent movement of sediment into the entrance of the harbor, and the absence of a

definite, deep channel leading toward the shore where wharfage may be built. Thus Provincetown harbor gradually is growing more shallow, and the harbor at Erie (Fig. 395) is kept open only by two jetties which modify the courses of the currents.

Few harbors are suited naturally to all the demands of present-day commerce. Tortuous channels must be straightened, and narrow and shallow channels must be dredged. The Ambrose channel in New York harbor has been opened recently. This new entrance to the leading Atlantic port of the United States involved the improvement of an old channel which had a depth of only 16 feet at low tide. This depth was sufficient only for light-draft vessels, like scows and towboats. The need for a better entrance led to the deepening and widening of the channel so that it now has 40 feet of water at low tide, and a width of 2,000 feet for a length of seven miles. The work was done by powerful dredges at a cost of about six million dollars. When the channel was opened, nearly all large vessels used it. In a single year more than 600 trips were made by vessels of such size that, before the opening of the Ambrose channel, they could have entered only by lightering part of their cargoes, or by waiting for very high tide. The channel from Philadelphia to the sea must be dredged to a depth of 35 feet in order to accommodate the largest ocean vessels. A plan is on foot to make a new port at the eastern end of Long Island, to accommodate steamers having such a length that docking facilities are no longer convenient in the limited space along the New York water front.

In many places the demands of commerce from lands bordered by regular coasts compel the expenditure of large sums for artificial harbors. Dover, England, has one of the greatest artificial ports in the world. There a series of concrete breakwaters more than two miles long enclose a harbor of nearly one square mile, with a minimum depth of 40 feet. The harbor cost more than $20,000,000. Its chief value is as a base for naval vessels at a strategic point on the English coast. A breakwater nearly two miles long has been constructed at Hilo, Hawaii, to protect shipping from the northeast trades. Similar extensive additions have been made recently to the works at Madras, to make that port equal to the other commercial centers of India.

Many ports once important have declined because of the changing conditions of commerce. To keep pace with the ever-increasing demands, large appropriations are made annually by our federal

government. From the standpoint of commerce, harbor improvement is one of the most important phases of government work. One of the first harbor appropriations in our country was $30,000 to erect public docks at Philadelphia. But regular appropriations for river and harbor improvements were not made by the federal government until about 1826, and not over $15,000,000 was so expended prior to 1860. Since that time, the amounts have been much larger.

Some ports have varied in importance as a result of changes in the routes of world commerce. Thus the discovery of the all-sea route to India in 1497 shifted the main scene of commerce from the Mediterranean to the Atlantic coast of Europe. Mediterranean ports, like Venice, declined to such an extent that they almost ceased to be factors in the handling of European commerce. The opening of the Suez Canal (1869), however, made the Mediterranean the shortest route for trade between western Europe and the Orient; it led to a great expansion in the volume of commerce between those regions, and gave a new stimulus to Mediterranean ports.

A similar condition is found in the Caribbean Sea and the Gulf of Mexico. These bodies of water bear to the Atlantic and the Americas a relation resembling that borne by the Mediterranean to the same ocean and the continents of the Old World. Here also a narrow isthmus blocks communication with the Pacific. The Panama Canal, however, will open this route. By shortening the distance from our Atlantic ports to most Pacific points, it will make the Caribbean a more important highway, and lead to expansion in trade between the two oceans. The neighboring ports, like those along the Gulf coast of the United States, will be stimulated by new traffic destined for Pacific points; they are also likely to benefit much, as handling centers, on account of their position as way-stations between the populous countries of the East and of the West. Many Pacific ports will be benefited similarly by freer communication with the Atlantic.

Questions

1. How is the importance of frontage on the ocean shown in the arrangement of countries? (Consult a political map of the world.)
2. Why is Holland better situated than Belgium for carrying on sea trade?
3. Why are the natives of the Malay archipelago expert boatmen? Why were the Incas of Peru not a seafaring people?
4. Why is the location of Montreal better than a place at the entrance to the Gulf of St. Lawrence for the development of a seaport?

5. What dangers threaten vessels plying along submerged coasts? Along recently elevated coasts?

6. How would a submergence of 500 feet affect the Mississippi River system?

7. What effect would an elevation of 200 feet have on Chesapeake Bay?

8. How can the direction of shore currents be determined from the outline of the coast? Explain in the case of Cape Hatteras and Cape Cod.

9. Why are there few important commercial centers on the coast between Cape Henry and Cape Florida?

10. What prevents Portland, Me., from being a leading commercial center?

11. Classify the leading seaports of the United States according to the kinds of harbors which they possess.

12. Why are some harbors in tropical regions, as Manila harbor, well protected at one season and not at another?

13. Which Gulf ports are likely to benefit most from the opening of the Panama Canal? Why?

14. What would be the probable effect on the ports of the Atlantic coast if the Appalachian Mountains were as high as the Sierra Nevadas?

15. Along what kinds of coasts are the dangers to shipping greatest? Why?

16. Along what kinds of coasts is the work of the Life Saving Service most difficult? Why?

17. Why would fishing villages be more likely to develop along the coast shown in Fig. 381, than along that shown in Fig. 380?

18. Which coast referred to in the preceding question is the more dangerous to navigation? Why?

19. Suggest the probable course of shore currents along the coasts shown in Figs. 395 and 400. Which harbor is likely to be affected the more seriously by shore currents? Why?

20. Suggest reasons for the movement of exports and imports by coasts and ports, as shown in Figs. 396 and 397.

21. Suggest reasons why New York is a great exporting and importing city, and why Galveston exports much but imports little.

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CHAPTER XX

DISTRIBUTION AND DEVELOPMENT OF THE LEADING INDUSTRIES OF THE UNITED STATES

Agriculture

Importance of agriculture. Agriculture is the most fundamental industry of the United States; it furnishes, directly or indirectly, most of what we eat and wear, and other needs are less important than food and clothing. More than ⅓ of the wage-earners of the country are engaged in agriculture (Fig. 401). The total value

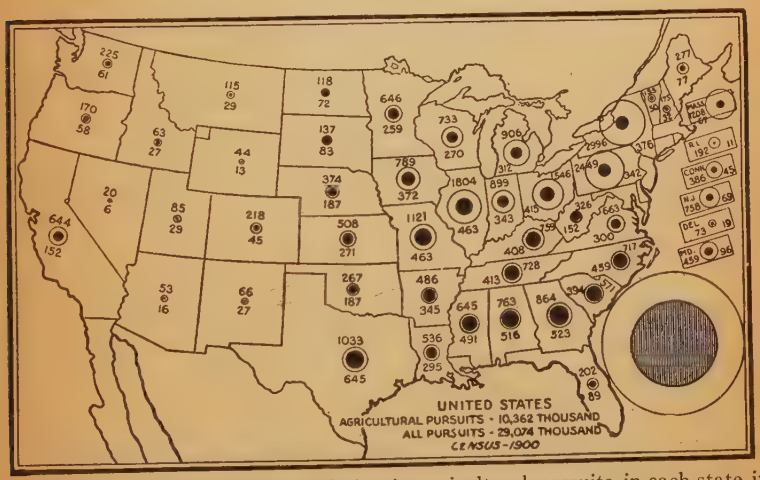

Fig. 401. Wage-earning population in agricultural pursuits in each state in 1900 shown by inner black circle, and by the smaller number adjacent; wage-earning population in all pursuits shown by the outer ring, and by the larger number adjacent. Numbers = thousands of wage-earners. (After Middleton Smith.)

of farm lands increased about ⅓ between 1900 and 1905, and is now estimated at between $25,000,000,000 and $30,000,000,000. About half the farm lands, or a little more than one-fifth the area of the country, is cultivated. Fig. 402 shows the relation of improved acreage to total farm acreage (including woodlots, etc.) in the different states.

The total value of all farm products has increased each year for more than a decade, and reached nearly $9,000,000,000 in 1910. This was more than double the figure for 1900 (Fig. 403). In 1910,

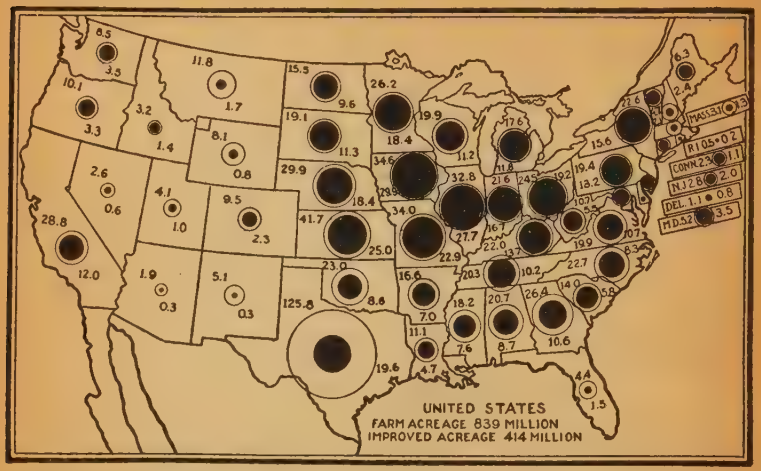

Fig. 402. Map showing relation of improved acreage (black circles) to total farm acreage (outer rings) in the different states in 1900. The smaller numbers adjacent to the circles = millions of acres of improved land; the larger numbers = millions of acres of farm land. (After Middleton Smith.)

the six crops leading in value were corn, cotton, hay, wheat, oats, and potatoes. The United States produces about $\frac{4}{5}$ of the corn

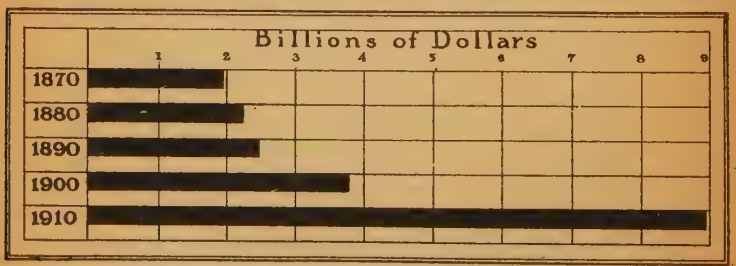

Fig. 403. Diagram showing total value of farm products in the United States for the census years 1870–1910.

of the world (Fig. 404), $\frac{3}{5}$ of the cotton (Fig. 405), $\frac{1}{4}$ of the oats (Fig. 406), and $\frac{1}{5}$ of the wheat (Fig. 407).

The leadership of the United States in agriculture is due to (1) the

Fig. 404. Map showing average annual production of corn in different countries (1903–1907). Figures in countries represent production in millions of bushels. (After Middleton Smith.)

Fig. 405. Average annual production of cotton in different countries (1903–1907). Figures in countries represent production in thousands of bales. (After Middleton Smith.)

Fig. 406. Average annual production of oats in different countries (1904–1908). Figures in countries represent production in millions of bushels. (After Middleton Smith.)

Fig. 407. Average annual production of wheat in different countries (1904–1908). Figures in countries represent production in millions of bushels. (After Middleton Smith.)

extent, variety, and high average fertility of its soils; (2) the favorable climate of most sections, with range sufficient to favor the production of many crops; (3) the facilities for marketing products; (4) the energy and ability of the farming people as a whole; and (5) the activity of federal and state agencies in introducing new plants, better seeds, and scientific methods of cultivation.

The United States Department of Agriculture has been a great help to the agricultural interests of the country. Agents of the department seek in foreign countries for new plants, suited to the special conditions of different parts of this

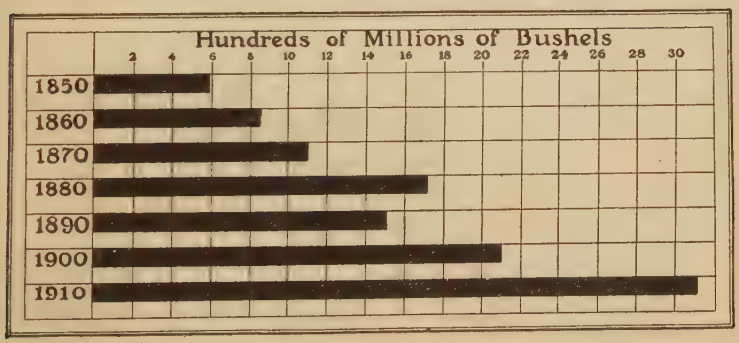

Fig. 408. Diagram showing production of corn in the United States, for the census years 1850–1910.

country. The department carries on investigations in many lines, and the results are made public through printed reports, field agents, agricultural newspapers, and in other ways. There are nearly 60 Agricultural Colleges and more than 60 Agricultural Experiment Stations in the United States, which have done much to advance agriculture. In a number of states, the elements of agriculture are taught in the public schools.

Leading Crops

The general distribution of crops throughout the United States is controlled largely by climate (pp. 188, 190, 193, 204). Their detailed distribution is influenced also by soil, topography, transportation facilities, market conditions, and other factors. It is practicable to consider here only the leading crops.

Corn. Corn is our most important crop — in total value, acreage, and amount grown. Fig. 408 shows the great increase in production since 1850. More than 300 varieties of corn are known, but only a comparatively few are grown in large amount. The

leading varieties thrive best where there are plentiful rains with prevailingly warm, sunny weather during the growing season, and in rich, well-drained soils. The "corn belt" is south of the "wheat belt," because the staple varieties of corn require a higher temperature and a longer warm season. Illinois, Iowa, Nebraska, Missouri, Kansas, and Indiana are the leading corn-producing states (Fig. 409). Production is increasing rapidly in the southern

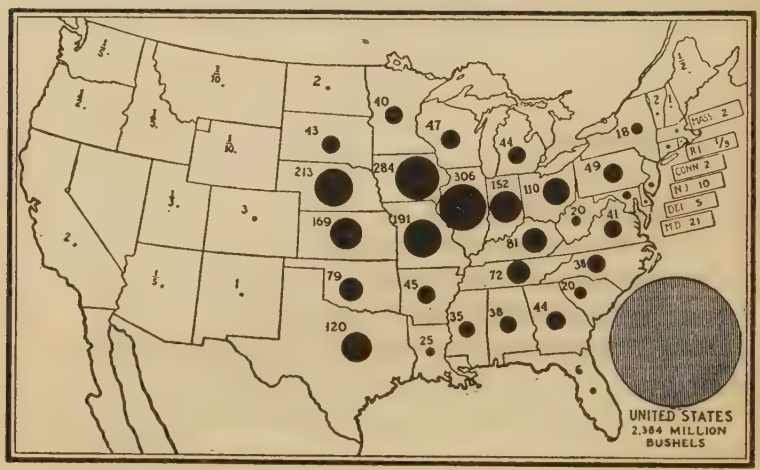

Fig. 409. Average annual production of corn in the different states (1899–1908). Figures in states represent production in millions of bushels. (After Middleton Smith.)

states, especially where the ravages of insects have made the growth of cotton uncertain. The average yield of corn per acre is about 25 bushels (1867–1906, 25.2; 1897–1906, 25.4). Experiments show that this can be doubled at least by the general adoption of better methods of tillage, careful selection of seed, and the use of varieties best suited to the places in which they are grown.

Because of the low price of corn, compared to its bulk and weight, little is shipped to distant markets. Most of it is used where it is grown, to feed stock. Corn is used also as a breadstuff, and in the manufacture of whiskey (p. 580), glucose, and other products.

Corn appears to be a native of the highlands of Mexico, whence its cultivation spread northward and southward at an early date. The colonists found it cultivated more or less by many of the Indians, and in many cases they promptly

began to grow it. A number of the successful English settlements of eastern United States probably would have failed but for this food plant. As settlement spread westward, corn was the staple crop of much of the frontier. It was easy to cultivate, and usually returned a relatively large yield. It was stored easily, easily prepared for food, and was nourishing both for animals and man. "The progress of our conquest of this continent would have been relatively slow had it not been for the good fortune which put this admirable food plant in the possession of our people."

Wheat. In the United States, wheat is the most important food plant. It probably originated and was cultivated first in Mesopotamia, but its culture spread in prehistoric times into other parts of Asia, and into Europe and North Africa. Its great value as food, the comparative ease with which it can be transported (Why?), and its power to adjust itself to new conditions, favored its wide and rapid dispersal. As a result of long cultivation and selection under different conditions, there are now more than 1,000 varieties of wheat, adapted to rather diverse conditions.

Wheats are commonly classified as *spring* and *winter wheat*, *red*, *white*, *hard*, and *soft*. In the northern interior states spring wheats chiefly are grown, for plants from seeds sown in the fall are "winter-killed"; farther south, much winter wheat is raised. In general, soft wheats, relatively rich in starch, are used in making flour, while the very hard kinds, rich in gluten, are used chiefly for the manufacture of macaroni (p. 204). The last is especially true of the durum wheat grown in the western Great Plains (p. 276). Hard and soft varieties are commonly mixed in making flour. The chief white wheat district is in the Pacific coast states.

Fig. 410 shows the average annual production (1899–1908) of wheat in the different states, and Fig. 411 shows the rapid increase in the total production since 1850. This increase has been due to (1) the demands of the increasing population, (2) the occupation of new areas suited to wheat culture, (3) the improvement and general use of farm machinery, and (4) the improved conditions for storing, transporting, and milling the grain. As in the case of most other crops, the average yield per acre of wheat in the United States can be increased greatly. For the ten years 1897 to 1906, inclusive, it was 13.8 bushels; during the same time it was 32.2 bushels in the United Kingdom, 28 in Germany, and 19.8 in France. During recent years the exportation of wheat from the United States has decreased, as the demands of the home market have increased. While the acreage devoted to wheat culture in the United States can be increased in the semi-arid sections, and wheat may be imported, the greater supply needed in the future must be obtained chiefly by securing larger yields in the districts where wheat is already grown.

The centers of cultivation for wheat and the other leading cereals have moved steadily westward (Fig. 412). Vermont, the Genesee Valley, and the Monongahela Valley were among the famous wheat-growing districts of early days, but they produce relatively little now. Early in the last century, Baltimore was the leading flour-making and flour-exporting city of the country. The Susquehanna and Shenandoah valleys furnished most of the wheat, water power developed at the "fall-line" ran the mills, and flour was sent in "Baltimore clippers" to European, West Indian, and South American markets. In the Interior, Wisconsin affords

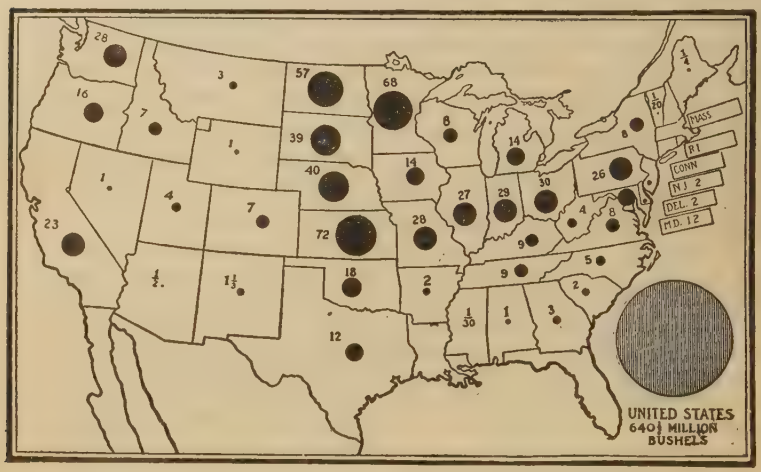

Fig. 410. Average annual production of wheat in the different states (1899–1908). Figures in states represent production in millions of bushels. (After Middleton Smith.)

a good example of a state which formerly produced much more wheat than now. It has been described as having been a "one-crop state" between the 1830's and 1870's, because it grew so much wheat. In the seventies, the difficulty of competing with the newer wheat lands farther northwest helped to bring about a great decline in wheat production in Wisconsin, and, in turn, the development of other agricultural interests.

Other cereals. *Oats* thrive best in a moist and relatively cool climate. They do fairly well in some of the southern states, where the climate, though warm, is moist, but do not grow well where it is both warm and dry. The chief area of production is in the northern Interior (Fig. 413). A small part of the crop is used as food for man, chiefly in the form of oatmeal; most of it is used as feed for animals.

Michigan (from Wisconsin to the Dakotas), and to the Pacific Coast (Fig. 414). In the former region it is used chiefly for the manufacture of malt liquor (p. 580), and in the latter for feed.

Among the minor cereals grown in the United States for their grains or for forage are *rice* (Fig. 415), *rye*, *buckwheat*, *kaffir corn*, and *millet*.

Hay. Hay includes various grasses and legumes which are "cured" as food for stock. The more important ones are timothy, clover, and alfalfa (p. 454). Some of the cereal grasses, like oats and barley, sometimes are grown for hay. Hay is produced in every state (Fig. 416), but the chief area is in the eastern half of the country, north of the 37th parallel. Although alfalfa is cultivated chiefly in the western part of the country, it probably will become of importance in the middle states in the near future, because of its relatively large yields per

Fig. 412. Map showing centers of production of corn, wheat, and oats (1850–1900).

Fig. 414. Average annual production of barley in the different states (1899–1908). Figures in states represent production in thousands of bushels. (After Middleton Smith.)

acre, its high nutritive value, and its importance in increasing the amount of nitrogen in the soil (p. 47).

Cotton. The cotton of commerce is the fiber which surrounds the seeds of the cotton plant. The value of the fiber and the

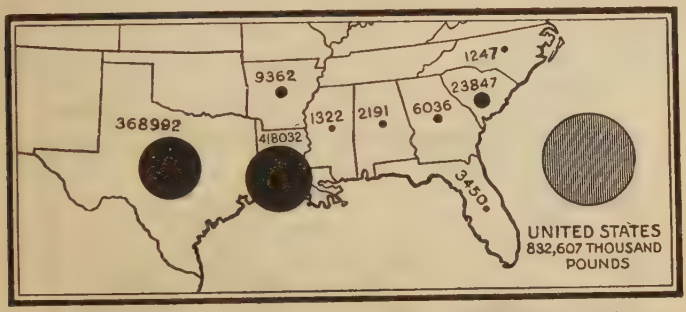

Fig. 415. Average annual production of rice in different states (1904–1908). Figures represent production in thousands of pounds. (After Middleton Smith.)

uses to which it is put depend on its length (½ to 2½ inches), strength, fineness, and color. The cotton plant requires a warm, moist climate, and a relatively long season free from frost. These

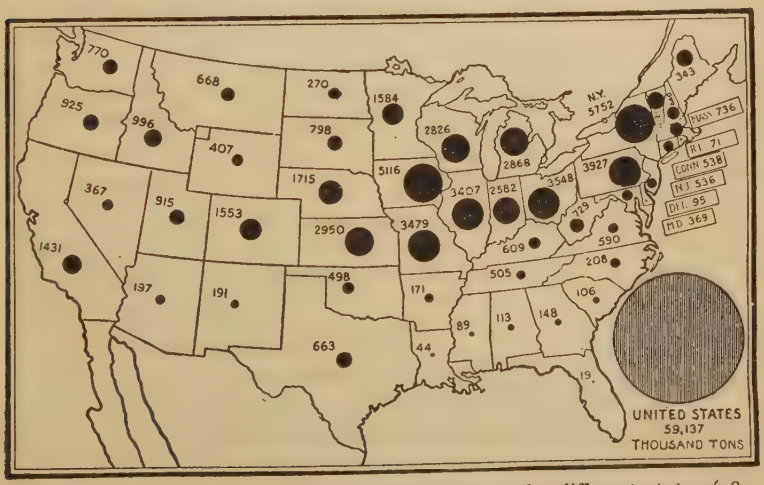

Fig. 416. Average annual production of hay in the different states (1899–1908). Figures represent production in thousands of tons. (After Middleton Smith.)

are the principal factors which limit the cotton-producing area of the United States to the southern part, east of the Great Plains (Fig. 417). In some other countries, the area of cotton culture may be extended.

Sea-island cotton, characterized by its long, fine fiber, thrives best on certain islands off the South Atlantic coast, partly because of the high humidity. Sea-island cotton is also grown some distance inland in southern Georgia and northern Florida (Fig. 418).

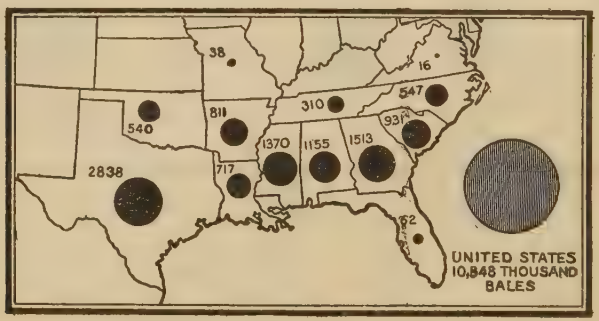

Fig. 417. Average annual production of cotton in different states (1899–1908). Figures represent production in thousands of bales. (After Middleton Smith.)

In general, the largest yields of cotton are obtained on the alluvial soils of the valley bottoms, and on the limey soils of the coastal plain (p. 273). Fig. 419 shows the changes in the production of cotton since 1800. About ⅓ of the cotton grown in the United States is manufactured at home (p. 577), and the rest is exported.

The cultivation of cotton in the United States began in the colonial period, but increased slowly until after the invention of the cotton gin (Eli Whitney, 1792) in this country, and of spinning machinery in England. The former made easy the separation of the fiber from the seed, enabling one man to do as much as 100 to 200 could do by hand. These things, coupled for some years with unusually high prices for cotton, caused a great increase in its production. The output of the United States increased from some 2,000,000 pounds in 1791 to 35,000,000 pounds in 1800, and 70,000,000 pounds in 1805. The development of the cotton industry meant also a greatly increased demand for slaves as field hands. The work in the cotton fields was simple, requiring little skill and few tools. In these and other ways it was adapted to slave labor, and, as years passed, cotton culture and slavery became mutually dependent. The need of new lands to meet the demand for cotton was a leading factor in the settlement of part of the Gulf Plains (p. 492). The Gulf Plain cotton crop increased from 5,000,000 pounds in 1811,

to 150,000,000 pounds in 1826. Cotton and slavery had become dominant factors in the economic, social, and political life of the southeastern states, and helped to separate their interests in many ways from those of the northern states. Thus, the New England cotton manufacturer (p. 577) demanded a tariff on imported goods to protect him against foreign competition; the southern cotton planter, who bought many of his supplies abroad, was injured by the tariff, and of course opposed it. The growing sectionalism between the North and South resulted in the Civil War.

Fig. 418. Map showing (by shading) areas reporting sea-island cotton in 1909.

Other vegetable fibers. Of the several plants beside cotton which are grown for fiber, only hemp and flax are cultivated to any large extent in the United States. Indeed, the latter is cultivated here almost entirely for its seed, from which linseed oil is obtained. In Russia and elsewhere, flax is produced chiefly for the inner bark fiber, from which linen cloths are made. The fiber of hemp is used to make twine, rope, bagging, etc.

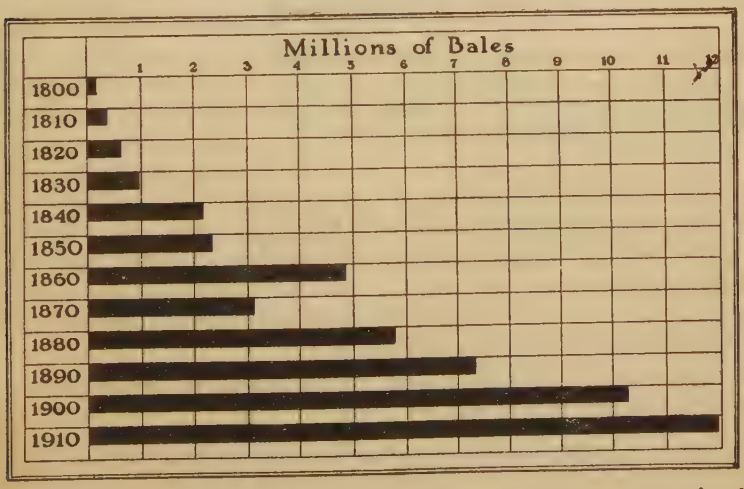

Fig. 419. Diagram showing production of cotton in the United States for the census years 1800–1910. A bale of cotton weighs 400 to 500 pounds.

Although both plants can be grown under rather a wide range of conditions, the cultivation of hemp in this country is confined largely to Kentucky, and that of flax chiefly to the Dakotas and Minnesota.

Tobacco. The United States is the leading country in the production of tobacco. It is grown in most states east of the 97th meridian, but a few produce the bulk of the crop (Fig. 420). The quality of the product varies greatly with the conditions of soil and climate, and with the care used in selecting the seed, cultivating the plants, and curing the leaves. Many grades are produced.

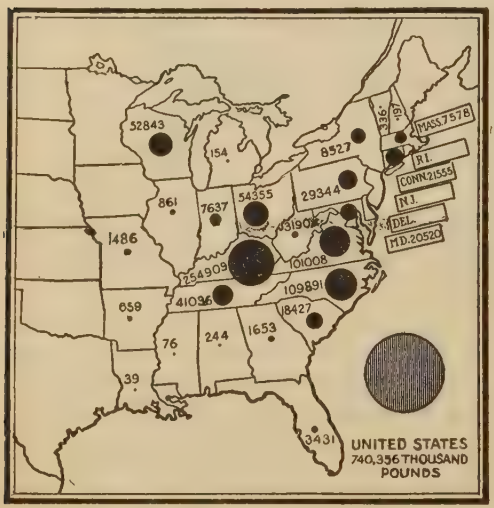

Fig. 420. Average annual production of tobacco in different states (1900–1908). Figures represent production in thousands of pounds. (After Middleton Smith.)

Vegetables and fruits. The growing of vegetables and fruits for distant markets and for consumption throughout the year has become an important industry mainly as a result of (1) improvements in transportation facilities, especially the perfection of refrigerator cars, and (2) the development of the canning industry (pp. 567, 576). It is impracticable to consider here the many fruits and vegetables now grown for commercial purposes in the United States. Some have been mentioned (pp. 188, 453, 458). Potatoes rank first in value among vegetables, and apples among fruits; the cultivation of both is distributed widely (Figs. 421 and 422).

The influence of refrigerator cars on the rise of industries involving the shipment of perishable commodities has been very great. The fruit and vegetable industries of the South and the deciduous fruit industry of the far West owe their development largely to the refrigerator car. It has enabled California, though one of the states farthest from the chief city markets, to become the leading fruit-growing state (p. 454). In 1877, a few bushels of peaches packed in moss were sent from Georgia to New York City by express, and two years later the experi-

Fig. 421. Average annual production of potatoes in the different states (1899-1908). Figures in states represent production in millions of bushels. (After Middleton Smith.)

Fig. 422. Map showing production of apples in the different states in 1899. Figures in states represent production in thousands of bushels. (After Middleton Smith.)

ment was tried of shipping them by express in refrigerator boxes. Clearly peach-growing in Georgia for the northern markets could not become important under such conditions of transportation. In 1882, however, the railroad companies began to furnish refrigerator cars to the peach-growers, and, as a result, the industry spread to many parts of the state. In many places, the refrigerator car helped change various fruits and vegetables from luxuries, obtainable during a short season only, to staple articles of food available during a long season, or throughout the year. For example, New York City formerly obtained cantaloups

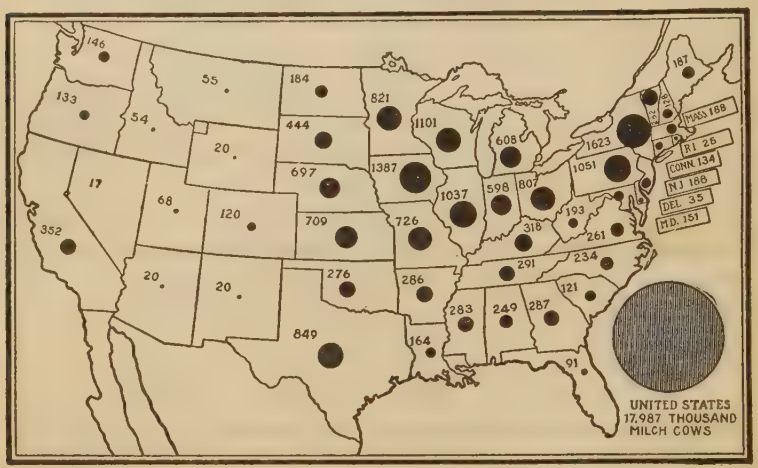

Fig. 423. Milch cows on farms and ranges. Average annual number in thousands (1899–1908). (After Middleton Smith.)

during a few weeks only from New Jersey, Delaware, and Maryland. Now the season for them in New York lasts from early May to late October, and some of them come from the Pacific coast.

Sugar plants. Sugar-cane is a tropical and sub-tropical plant, and its cultivation in the United States is confined to the Gulf States, Georgia, and South Carolina. Louisiana grows more than $^9/_{10}$ of the total crop of the country. In 1910, 750,000,000 pounds of cane-sugar were produced in the United States.

The sugar-beet was brought into this country some forty years ago from central Europe, and in recent years its cultivation has spread rapidly. Colorado, Michigan, California, Utah, Idaho, and Wisconsin lead in the production of sugar-beets, but the industry has some importance in a dozen other states. In the West, sugar-beets are grown largely on irrigated lands. The production of

beet-sugar in the United States increased more than five-fold between 1900 and 1908, amounting, in the latter year, to some 900,000,000 pounds.

Animal Products of Farm and Range

Cattle. Cattle are raised in the United States chiefly for beef, dairy products, and hides. Fig. 423 shows that most of the milch cows are in the more densely settled eastern half of the country, and

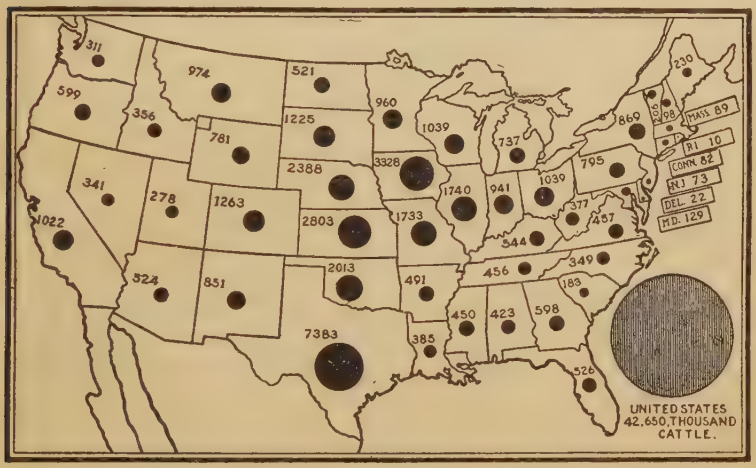

Fig. 424. Cattle other than milch cows on farms and ranges. Average annual number in thousands (1899–1908). (After Middleton Smith.)

that in the eastern half, most are in the northern states. The many cities and villages of the North Atlantic and North Central States require an enormous quantity of milk, and cannot draw their daily supplies from great distances. Herds may be kept at a greater distance from market in connection with the manufacture of butter, cheese, and condensed milk (p. 576).

Fig. 424 indicates the distribution of cattle other than milch cows. This map differs from the preceding one in the smaller numbers for the North Atlantic States and the greatly increased numbers in the Great Plains and western States. Large parts of the Great Plains afford the best environment for cattle in the country, and much of the land, furthermore, cannot be used for growing crops (p. 498). Extensive areas are required for grazing large herds of cattle, and

with the growth of population in the East much land so used in earlier years has been devoted to other purposes. The United States has more than $^1/_6$ of the world's cattle.

Sheep. Sheep are raised for mutton and wool. During the last fifty years a great change has occurred in their distribution. The number in most of the middle and eastern states has decreased, while in the western states it has increased greatly. At the beginning

Fig. 425. Sheep on farms and ranges. Average annual number in thousands (1899–1908). (After Middleton Smith.)

of the period, the West had less than $^1/_{10}$ of the sheep of the country; now it has more than $^2/_3$ (Fig. 425; What are the probable reasons for the change?). The annual wool clip of the United States is more than 300,000,000 pounds; nearly all of it is used in American factories, and in addition much is imported.

Swine. About $^2/_5$ of the swine of the world are in the United States. While they are raised more or less in every state, the great swine region (Fig. 426) is the same as the leading corn-producing section (Fig. 409), for corn is the chief food for swine. Nearly half the corn crop is disposed of in this way.

Horses. A comparison of Fig. 427, showing the distribution of horses in the United States, with Fig. 402, showing the improved acreage and its relation to the total farm area in the different states,

indicates that the number of horses in the different states corresponds roughly to the amount of land cultivated. This is less striking in some of the southeastern states, where many mules are used to cul-

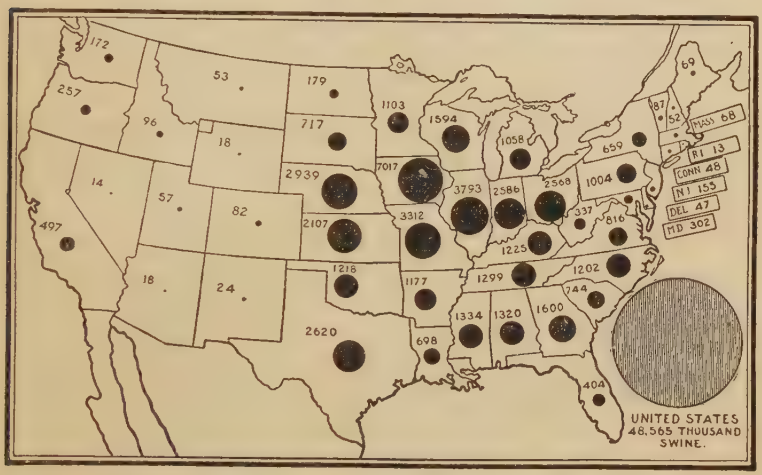

Fig. 426. Swine on farms and ranges. Average annual number in thousands (1899–1908). (After Middleton Smith.)

Fig. 427. Horses on farms and ranges. Average annual number in thousands (1899–1908). (After Middleton Smith.)

tivate the land, because they can stand hard work in that climate better than horses.

The total value of farm animals in the United States in 1910 was estimated at $5,138,486,000.

Poultry and eggs. Poultry and eggs are incidental products of most farms. In recent years poultry-raising has become also a specialized industry of importance, particularly in the leading corn-producing states and near some of the larger cities. The value of the poultry and eggs produced yearly in the United States is about $140,000,000 and $150,000,000, respectively.

Forest Resources and Lumbering

The forests of the United States have been a chief factor in the progress of the country. They have furnished firewood and materials for buildings, furniture, implements, utensils, vehicles, fences, paper, posts, poles, cross-ties, ships, railroad cars, bridges, sidewalks, etc. Our dependence on the forests for material for many things is less than formerly. Thus, coal is now used extensively as fuel; brick, stone, and cement for buildings; iron and steel for ships, freight cars, bridges, etc.; wire for fences; and cement for sidewalks. Nevertheless, the aggregate yearly drain upon the forests has increased with great rapidity. The United States is the leading wood-producing country, and it is estimated that its total annual consumption (including that destroyed by forest fires) may amount to 100,000,000,000 or more board-feet.[1] The total value of the forest products in 1909, including firewood, fence-posts, and other miscellaneous items, is estimated at about $1,250,000,000 — some 19 per cent more than the corresponding estimate of values for the products of 1908.

Forest regions of the United States. Forests still cover about ¼ the area of the United States. Although the present extent of forest land is more than ⅗ the original area, the amount of merchantable saw timber remaining probably is not more than half the original supply. The last fact is particularly significant in view of the comparatively short time during which the forests of the country have been exploited. Fig. 428 shows the five great forest regions of the country. Not all the land within any of these belts was forested originally, and much has been cleared. The unshaded portions of the map are without trees, for the most part.

[1] A board-foot is a piece of wood one foot square and one inch thick.

(1) The Northern Forest contains both soft and hard woods, though the former have been of most importance commercially. The leading kinds of trees include white pine, red pine, spruce, hemlock, cedar, balsam-fir, birch, cherry, and sugar maple. (2) The Hardwood Forest contains oak, elm, hickory, cottonwood, maple, basswood, chestnut, ash, etc. Not all the woods of the Hardwood Forest are hard; cottonwood and basswood, for example, are soft. (3) In the Southern Forest the yellow pine predominates greatly, but in places suited to their growth are cypress, oak, gum, magnolia, and other hardwoods. (4) The Rocky Mountain

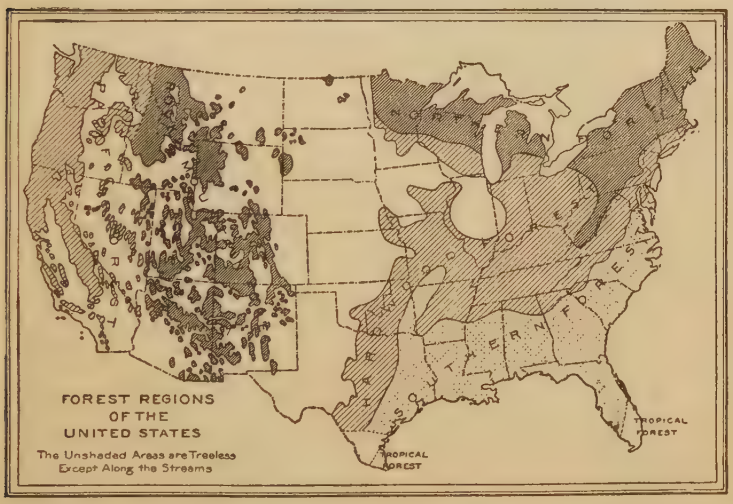

Fig. 428. Map showing forest regions of the United States. (U. S. Forest Service.)

Forest is almost entirely coniferous; leading forms are the western yellow pine, lodge-pole pine, Douglas fir, larch, spruce, and western red cedar. (5) The Pacific Forest is also coniferous, consisting chiefly of Douglas fir, western yellow pine, redwood, western red cedar, sugar pine, etc. Fig. 429 shows the lumber production for 1909, by kinds of wood. The cut of yellow pine equalled that of the four next most important kinds; white pine, long in the lead, ranked fourth. These facts reflect the rapid development of lumbering in the southern and western states, and its decline in the Lake states (pp. 558–559).

Distribution of the lumbering industry. As would be expected from the distribution of the forests, lumbering is carried on in every state, but, as Fig. 430 shows, the production varies greatly. The nineteen states which in 1909 cut more than a billion board-feet of lumber each, furnished together more than ⅘

of the entire cut for the United States. Great changes in the distribution of the industry have occurred, for as the forests in one region have become depleted, new areas have been opened up. For many years the northeastern states led in lumbering, which was particularly important in Maine and New York. Since 1850, the industry has declined greatly in that region. The forests of the Great Lakes region were the next to be exploited extensively (p. 432), furnishing in 1880 about ⅓ the lumber cut of the country. Michigan and Wisconsin became in turn the leading lumbering state; now they rank tenth and eighth, respectively (Fig. 430). At present, the southern states contribute most to the lumber output (Fig. 430), but the industry is expected to reach its climax there within a few years, and already the Pacific states are large producers. Indeed, Washington now leads in the business, while Oregon ranks ninth and California eighteenth. The accompanying table shows the changes that have occurred since 1850 in the percentage of the total cut furnished by the leading lumbering sections.

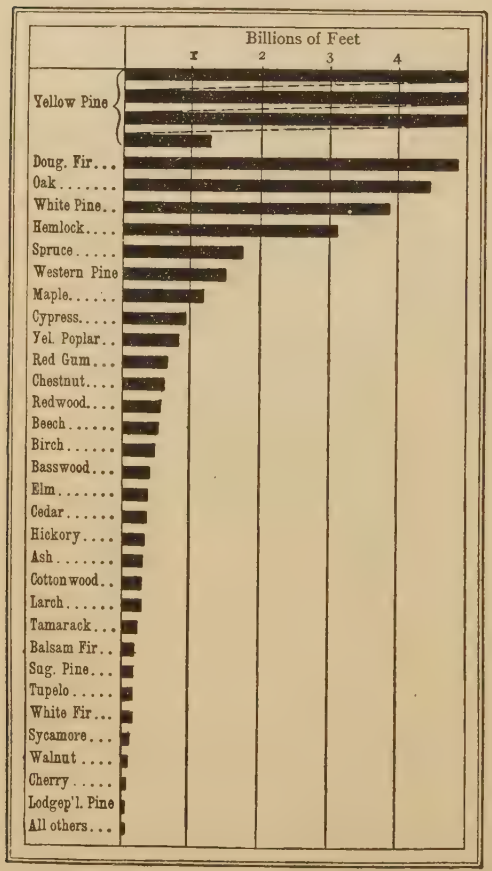

Fig. 429. Diagram showing lumber cut for 1909, by kinds of wood. (U. S. Forest Service.)

Year	Northeastern States	Great Lakes States	Southern States	Pacific States
1850	54.5%	6.4%	13.8%	3.9%
1860	36.2%	13.6%	16.5%	6.2%
1870	36.8%	24.4%	9.4%	3.8%
1880	24.8%	33.4%	11.9%	3.5%
1890	18.4%	36.3%	15.9%	7.3%
1900	16.0%	27.4%	25.2%	9.6%
1905	14.6%	20.4%	27.9%	13.8%

Conservation of forest resources. About 260 cubic feet of wood per capita per year are consumed in the United States. This is greater than the per capita rate of consumption in any other country, about ten times that in France, and seven times that in Germany. Stated in another way, we are taking, on the average, 40 cubic feet of wood per acre per year from our forests. Since the average growth in the forests of the United States is not at present greater than 12 cubic feet per acre per year, it is evident that we are consuming wood more than three times as fast as it is being produced in our forests. The United States cannot in the long future count on foreign sources of supply for ordinary structural timber, for other countries probably will need all they can grow. Therefore, if there is to be a permanent supply of wood in this country, our consumption cannot continue to exceed the production of our forests. Clearly, every means of reducing the drain upon the forests, and every means of increasing their production, should be encouraged.

Altogether apart from a supply of timber, the preservation of forests in many places is highly desirable (1) to reduce soil erosion and the resultant deposition of waste on lower lands, in stream channels, and in harbors (p. 267); (2) to make floods less frequent and less dangerous (p. 366); and (3) to help equalize the flow of streams important for navigation, power (p. 444), or irrigation (p. 455).

The principal ways in which the forest resources of the United States should be conserved may be indicated briefly. (1) Losses from fires should be reduced (Fig. 431). These losses are of several kinds. (a) The *average* annual loss of *merchantable* timber is estimated at about $50,000,000; in some years (e.g., 1910) it has been much greater. In addition, many lives have been lost in some forest fires, and villages have been consumed. (b) Great loss is involved in the damage to young trees and seedlings. (c) After high-class timber is burned off an area, the latter may be occupied by inferior kinds of timber. (d) The humus in the soil may be consumed, reducing or destroying the fertility of the latter. (e) Erosion may increase on burned-over areas, and the flow of streams may become more uneven.

Forest fires are started by sparks from locomotives, by careless campers and hunters, by careless clearing and brush burning, by lightning, and in other ways. Save those due to lightning, nearly all may be prevented. So far as its funds permit, the Forest Service maintains a patrol in the National Forests, partly with a view to detecting fires at their beginning, and fighting them while they are still small. Some state and private forests also are patrolled during the dry season.

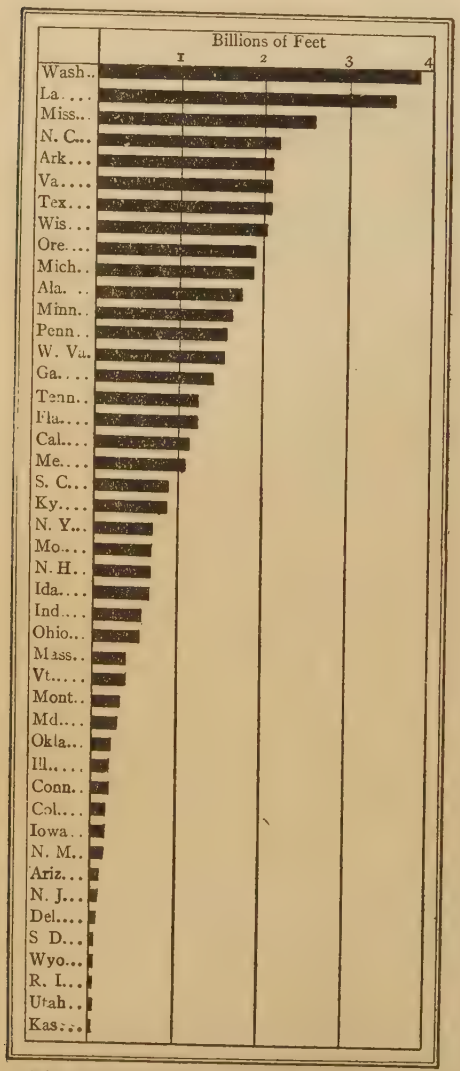

Fig. 430. Diagram showing lumber production by states in 1909. (U. S. Forest Service.)

(2) Waste in logging should be reduced so far as practicable. At present it averages about 25% in the timber holdings of individuals and companies, and something less than 10% in the National Forests. In connection with logging operations, young trees should be protected, and seed trees should be left. (3) The wastes in sawmills and wood-using industries (p. 578) should be reduced. (4) Refuse wood may be used in making many things now manufactured from good timber (p. 579). (5) Wherever practicable, forest areas should be kept fully stocked with rapid-growing and valuable species of trees. In this way the production of wood in existing forests may be increased greatly. (6) In many places, cut-over or burnt-over areas should be re-forested. (7) Posts, poles, cross-ties, mine timbers, pilings, shingles, etc., may be treated with some preservative substance, such as creosote or zinc chloride, and thus rendered less subject to decay and to the attack of insects. Wood treated in this way lasts 10 to 18 or more years longer than wood not so treated, so that its period of use is increased in

many cases 2 to 4 times, and in some cases much more. The general adoption of the practice of treating with preservatives wood used in the above ways would not only lessen the drain on the forests, but also give value to much inferior timber, otherwise nearly worthless. (8) The enormous annual waste of forest resources caused by insects can be reduced greatly. (9) The wasteful methods generally followed in the turpentine industry (p. 569) should be abandoned. (10) For many purposes, other material may be substituted advantageously for wood (p. 280). (11) Standing timber is taxed in most states each year, and this leads owners in many cases to cut all their timber and put it on the market as soon as possible. Before the principles of scientific forestry can be adopted generally, these tax laws must be reformed. (12) Recently much has been done to conquer the diseases of forest trees, and much more may be done in the future.

Fig. 431. Effects of hurricane and fire in a heavy stand of white pine on the Little Fork of St. Joe River, Coeur d'Alene National Forest, Idaho. (U. S. Forest Service.)

The Fishing Industries

Nature and general distribution. Fishing on a commercial scale is carried on from many points on the coasts of the United States, and on many inland streams and lakes. The total annual

value of the products of the fisheries has exceeded $60,000,000 in recent years, the products of the coast and ocean fisheries making nearly ¾ of the total. The products include not only food-fishes, but the commercial products derived from all other marine and fresh-water animals. About ²/₅ of the products are furnished by animals other than fishes, such as clams, mussels, oysters, lobsters, shrimps, sponges, whale products, and fur-seal pelts. The leading species of fish of commercial importance are salmon, cod, shad, menhaden, mackerel, squeteague (or sea trout), haddock, herring, and trout.

Most marine fishing industries are the result of (1) the existence of extensive shallow waters off shore, to serve as feeding and breeding grounds for large numbers of fish; (2) convenient harbors affording safe havens for fishing boats; and, where the industry is dependent on the sale of fresh fish, (3) nearness to large centers of population. With present-day facilities for transportation and refrigeration, the last point is less important than formerly. With all these advantages, the New England coast always has been noted for its fishing interests, while much of the Pacific coast, with few harbors, and with deep waters relatively near shore, has no important fishing fleets.

Where poor soil, rugged surface, or rigorous climate has made farming in coastal regions unprofitable, the people have turned to the ocean for a living. They become fishermen, develop into expert sailors and navigators, and supply men for the great merchant fleets of the world.

Atlantic coast fisheries. Since early colonial days, the fishing industries of the Atlantic coast have centered in New England (Fig. 432). Cod, haddock, mackerel, and herring are taken in largest quantities.

Most of the early settlements along the eastern coast of New England had fishing fleets, and many of them depended almost entirely on the industry. For many years, cod was the leading export of New England. The better fish were taken to the Catholic countries of southern Europe, while those of poorer quality were sold in great quantities in the West Indies to feed the slaves. Here salted cod was cheaper and more wholesome than meat, and would keep much longer. In early days many fishing towns were scattered along the New England coast at points where the advantages of harbors and nearness to good fishing grounds were combined, and the industry was carried on chiefly from small boats near land. As the supply of fish near at hand became inadequate, larger vessels were built for operations on the distant banks, and the industry centered in a few places having superior advantages. Gloucester has the best harbor on Cape Ann, and was the first fishing port of the district to secure railroad communication with Boston. Accordingly, the industry developed rapidly there, while it declined at

less-favored neighboring towns. To-day, Gloucester and Boston are the most important fishing ports in the United States.

The whaling industry was important in New England for many years, although insignificant now. It was concentrated chiefly on the southeastern coast, with Nantucket and New Bedford as leading centers. Several factors contributed to its rapid decline during the third quarter of the last century, especially (1) the growing scarcity of whales and (2) the fact that the discovery of petroleum in Pennsylvania and other states diminished greatly the demand for whale-oil.

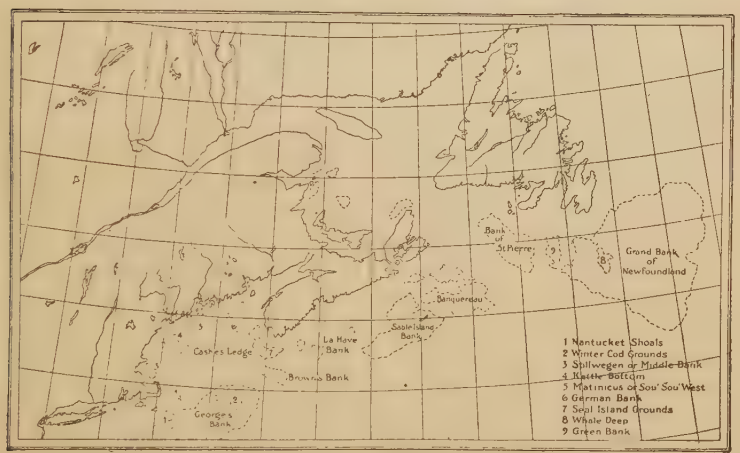

Fig. 432. Map showing (by broken lines) principal fishing grounds off the coasts of New England, Nova Scotia, and Newfoundland. (After McFarland.)

The oyster is the most important shell-fish. It thrives best in relatively warm waters, and in quiet, shallow estuaries and bays, such as those between Long Island Sound and Chesapeake Bay. Some $^4/_5$ of the oysters marketed each year in the United States come from this section of the coast. The industry formerly depended entirely on natural beds of oysters. As the natural supply declined, the practice grew up, in many places, of "planting" young oysters, and leaving them to mature.

Pacific coast fisheries. The salmon fisheries are the most important ones on the Pacific coast. Cod and halibut are the other principal species caught. The salmon industry is centered in Alaska, about the shores of Puget Sound, and on the Columbia River (Fig. 433). Most of the fish are caught in traps and weirs during the spring or summer run, when they ascend the rivers to spawn. At such

times, the waters sometimes have been so congested with salmon that the nearby canneries (p. 568), working night and day, have found it difficult to handle the fish. In 1909, for example, a trap near Bellingham, Washington, contained in one catch more than 100,000 salmon. Canned salmon is the largest fish export of the United States.

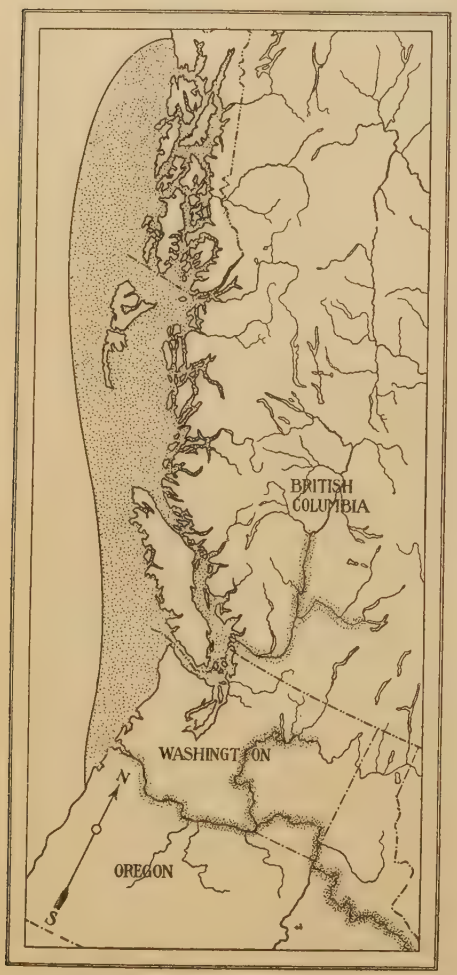

Fig. 433. Map showing (by shading) principal salmon waters of the Northwest.

In Alaska, the salmon fisheries rank next to gold mining in value of output. The total value of their product since 1868 is said to be more than $130,000,000.

The largest fur-seal herd in the world uses the cool, moist Pribilof Islands (Bering Sea) as a breeding ground, but the estimated number of animals in it was reduced from some 5,000,000 in 1867 to about 200,000 in 1905. In recent years steps have been taken to prevent the extermination of the herd, and to put the fur-sealing industry on a reasonable and permanent basis.

Mining, Quarrying, etc.

The principal mineral resources of the United States, together with their uses and economic significance, were noted in Chapter XIII. The mining and quarrying of these resources afford employment to hundreds of thousands of people, and furnish raw

material or fuel for many other industries. The total value of the mineral products of the United States in 1910 was about $2,003,000,000. The accompanying table shows the production of the leading mineral substances in that year.

	Quantity	Value
Pig Iron	27,303,567 long tons	$425,115,235
Copper	1,080,159,509 pounds	137,180,257
Gold	4,657,018 troy ounces	96,269,100
Lead	372,227 short tons	32,755,976
Silver	51,137,900 troy ounces	30,854,500
Zinc	252,479 short tons	27,267,732
Aluminum	47,734,000 pounds	8,955,700
Bituminous coal	417,111,142 short tons	469,281,719
Pennsylvania anthracite	75,433,246 long tons	160,275,302
Natural gas	.....	70,756,158
Petroleum	209,556,048 barrels	127,896,328
Clay products	.....	170,115,974
Cement	77,785,141 barrels	68,752,092
Stone	.....	76,520,584
Other structural materials	.....	40,821,793
Gypsum	2,379,057 short tons	6,523,029
Phosphate rock	2,654,988 long tons	10,917,000
Salt	30,305,656 barrels	7,900,344
Mineral waters	62,030,125 gallons	6,357,590

Distribution of mineral industries. In general, the distribution of mineral deposits (pp. 278-288) controls that of mining and quarrying, but whether or not a given mineral deposit can be worked profitably depends on several things. Chief among these are (1) its size, (2) its quality, (3) its location, (4) the cost of working it, and (5) market conditions. The relative importance of these factors varies greatly with different minerals.

(1) In many places minerals of value occur in quantities too small to mine. Other things being equal, the opening and equipment of a modern mine might be justified by a very small deposit of a valuable mineral, like gold or silver, but might not be warranted by a vastly larger deposit of a cheap mineral, like iron. (2) There is much low-grade ore and coal that cannot be mined profitably in competition with better material of the same kind. For example, the United States is estimated to have more than 75 billion long tons of low-grade iron ore, not available (i. e., not workable with profit) under existing conditions, as against less than 5 billion tons which are available. (3) The importance of location is greatest in the case of minerals

which are abundant and cheap, and least in the case of those of great value. Thus iron ore which could be mined with a small profit if in Pennsylvania or near the shores of the Great Lakes, probably could not be mined if in Utah. On the other hand, gold offers great value in small bulk, and so can be transported easily. In recent years, therefore, it has attracted thousands of men to remote sections of Alaska, where most other minerals could not be mined with profit. Similarly, the discovery of gold in California in 1848 brought nearly 50,000 miners there in 1849, added a new state to the Union in 1850, and gave it a population of 360,000 in 1860. (4) Relatively cheap minerals are mined only where they occur in favorable positions, rather near the surface; those of greater value justify deeper mines and greater expense. In classifying the coal lands of the Public Domain, the United States Geological Survey has taken a depth of 3,000 feet as the present limit for coal mining. Some of the copper mines of the Lake Superior region are more than a mile deep. (5) The output of many mines and quarries is affected greatly by market conditions. This is illustrated in a general way by the fact that the total value of the mineral products of the country declined from $2,071,000,000 in 1907 to $1,595,000,000 in 1908, largely as a result of the business depression which began late in 1907.

The influence of mining on the distribution of population and the growth of cities is discussed elsewhere (pp. 478, 499, 590, 599).

Manufacturing Industries

Growth of manufacturing industries. For many years, most of the manufacturing done in the United States took the form of household industries. The clothing, utensils, and implements used by the great mass of the people were largely "home-made," as is still the case in certain backward sections (p. 471). Some manufacturing was done in factories even in the colonial period, and manufactured goods were imported from other countries, especially for the use of the wealthier people. By 1820 or 1825, the factory system was established throughout much of the country then settled. Since 1850, and especially since 1880, the manufacturing industries of the United States have grown with great and increasing rapidity (Fig. 434), until now it ranks first among manufacturing countries. The total value of manufactured products for the coun-

try amounted, in 1905, to nearly $15,000,000,000. The industrial growth of the last half-century has been due to (1) the increase of population; (2) the improved financial condition and higher standard of living of the people; (3) the increasing supply of raw material; (4) the improvement of transportation facilities; and (5) the growing demand abroad for American goods.

The Location of Industries

Many manufacturing centers specialize in a few products. Thus Brockton, Massachusetts, is the leading boot and shoe center; Grand Rapids, Michigan, is famous for its furniture; and Peoria, Illinois, has the largest distilleries. In some cases, as in those cited, the

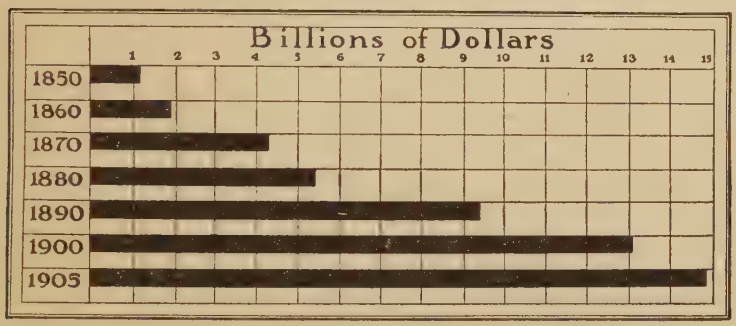

Fig. 434. Diagram showing total value of manufactured products in the United States for the census years 1850–1905.

reasons for the development of special industries in certain places are clear; in others, the causes are obscure. In general, the most important factors influencing the location of manufacturing industries are (1) distribution of raw material, (2) command of power, (3) accessibility of market, and (4) a supply of labor.

Distribution of raw material. The influence of the distribution of raw materials in locating the industries which use them is greatest in the case of (1) perishable raw materials, and (2) raw materials that are too bulky and too cheap to be carried far to factories. (1) If prepared and handled carefully, fresh fruits and vegetables may be sent long distances in refrigerator cars (p. 550). But it is impracticable to do this with the large quantities used in the canning, preserving, and allied industries. Hence these indus-

tries are located, for the most part, near the places of production. Thus, canning and drying fruit and making wine are important industries in California. Indeed, California furnishes about $^9/_{10}$ of the dried fruit and some $^2/_3$ of the wine made in the United States. In New Jersey and Delaware $^3/_4$ of the total canned product are tomatoes. Similar influences appear in the case of many animal products. The centering of slaughtering and meat packing in Chicago, South Omaha, and Kansas City is due partly to the losses which result from shipping live animals long distances. Butter, cheese, and condensed milk are manufactured extensively where large quantities of milk are produced, as in New York, Wisconsin, and Iowa.

The salmon-canning industry of the Pacific coast affords a striking illustration of the fact that the source of supply of a perishable raw material may control the location of the factories using it. The industry has moved northward as the source of the main supply of fish has shifted. Beginning in California in 1864, the industry soon spread to the Columbia River and to Puget Sound. Then the supply of fish began to fail, and the canning business declined in consequence, first in California, next in Oregon, and finally in Washington. Now the center of the industry is in Alaska, where nearly $^3/_4$ of the salmon packed in the United States are canned.

(2) Among the raw materials that are too bulky or too cheap to be carried economically to distant points are many of the products of the quarries, mines, and forests. Hence the industries which use these materials are located in most cases near the sources of supply. In some cases, on the other hand, special conditions make it practicable to take bulky raw material to remote manufacturing plants. Thus granite from Massachusetts or marble from Vermont is shipped profitably for monumental purposes throughout the country, because when cut and polished in a local yard a single piece may have a market value of hundreds of dollars. Again, it may be feasible to take bulky raw material to distant points because of exceptional facilities for cheap transportation, as in the case of the iron ore of the Lake Superior region (pp. 412, 431).

The tendency of wood-working industries to keep close to the lumbering districts is indicated by the distribution of saw-mills, wood-pulp mills, the turpentine industry, charcoal burning, and, less strikingly, furniture making. The wood-pulp industry was most important originally in western Massachusetts, and later in Pennsylvania, but as the supply of pulp-wood decreased, the industry became more important elsewhere. It is now centered in Maine, northeastern New York, and Wisconsin, where spruce and hemlock, the principal woods used in the industry, are more abundant. These sections have the additional advantages of abundant water power and relatively near markets for the finished products. The manufacture of furniture was carried on chiefly in the East until some twenty years ago,

with New York, Philadelphia, Cincinnati, and Boston the leading centers. Now Chicago stands well ahead of New York, and Grand Rapids, where 1/5 of the population is employed in furniture-making (p. 440), is a close third. This migration of the industry followed the shifting of the center of lumbering from the northeastern states to the Great Lakes region (p. 558). The recent decline of lumbering in the region of the Great Lakes, and its growth in the Gulf states and northwestern states (p. 558), have led to a rapid development of furniture-making in the latter sections. The manufacture of tar, pitch, and turpentine has long been an important industry in the South. These commodities are known in commerce as "naval stores," because in early days the tar and pitch were used to fill the seams of ships, so as to make them water-tight. They are made chiefly from the sap of the long-leaf pine, and this is obtained, in most cases, by frequently making needlessly large cuts in the lower part of the trunk. The average period during which a given tree furnishes sap under this method is only four years, and this has caused a steady migration of the center of the turpentine industry. North Carolina led until about 1850; then South Carolina came to the front, reaching its maximum production about 1880. From South Carolina the industry spread into Georgia, where it is just beginning to decline. Now Florida leads, and the industry is spreading rapidly into Alabama and Mississippi. The Forest Service has developed new methods of obtaining the sap from smaller cuts. The general adoption of these methods will increase greatly the duration of the industry in a given locality.

Most ores, except iron, have relatively high values for small bulk, but as they come from the mine, they are likely to be associated with much worthless material. Hence the metallic matter in most cases is partly separated (i.e., is *concentrated*) from the waste, at the mine. It may also be smelted (metal extracted from the ore) at the mine, but since in its concentrated form it is commonly valuable enough to bear rather heavy freight charges, it is shipped in many cases to some big smelter, where large-scale operation reduces the cost. Refining the metal may be done in turn far from the smelter. Thus, silver ore mined in Leadville, Colorado, may be concentrated at or near the mine, smelted in Pueblo, refined in Jersey City, and manufactured into jewelry in Providence, Rhode Island.

The source of many raw materials of high value has little if any influence on the location of the industries which use them. This is determined by other factors.

Many illustrations might be given. The United States produces no raw silk for the many silk mills of New York, New Jersey, and Pennsylvania. New York and Philadelphia have important sugar refineries, but there are no cane-fields nearer to them than the Gulf coast. Lowell, Massachusetts, manufactures large quantities of woolen goods, although New England now raises few sheep (p. 554).

Influence of power resources. Available power may be the leading factor determining the location of manufacturing plants which use raw material suited to economical transportation. Water power determined the location of many of the older manufacturing centers of New England (p. 440). Some of these places had small power resources, and depended on the local supply of raw material;

such places have declined. Others have continued to grow because they had larger power resources and were so situated that, as transportation facilities were improved, they could use raw materials from increasingly distant points, and could bring in coal to supplement their water power. There are said to be more than forty important manufacturing cities in southern New England that can trace their start to an early advantage in water power. Nearly all of them now use much more steam power than water power.

The use of coal and steam power in manufacturing increased rapidly after 1850. The growth of railroads steadily increased the number of places which could obtain coal for manufacturing, and also made cheaper the movement of raw materials to places situated favorably with respect to supplies of coal. The advantage of large deposits of good coal has had much to do with the remarkable industrial development since 1850 in the region extending from western Pennsylvania to Illinois. The use of other mineral fuels for industrial purposes also has located certain manufactures. Thus the discovery of natural gas in western Pennsylvania, Ohio, Indiana, and West Virginia attracted many industries because of the cheap and excellent fuel offered. In many places the supply of natural gas failed after a few years, and as a result many factories were abandoned or moved; some of the larger ones continued to operate by bringing in coal.

The discovery of natural gas in eastern Indiana in 1887 started a short-lived "boom" in that section. "Thus scores of industrial villages sprang up from nothing. At the same time sleepy rural towns multiplied population by ten and were transformed into cities with metropolitan conveniences and airs. . . . The whole country was lighted with flaming torches which it was not worth while to turn off day or night. The stock in many a farmer's barnyard enjoyed the illumination of a quantity of gas which would have run a small factory. . . . Half of the whole supply was wantonly wasted and legislation was too tardy and inefficient to check it. In twenty years the gas was practically exhausted. Plants and villages were abandoned. Houses were torn down for fuel or dismembered and transported to be set up again in another place. . . . Many plants were removed across the state to the coal fields, and in the case of those that did not go to the coal, the coal went to them." (DRYER: *Jour. of Geog.*, Vol. IX, p. 21.)

California is beginning to feel the benefit of the large supplies of cheap oil discovered there within the last few years. Formerly, the industrial development of the state was retarded by the fact that much fuel had to be imported from foreign countries at relatively heavy expense.

As the supply of mineral fuels diminishes, hydro-electric power will be used more and more in manufacturing (p. 442). But the ease of transmitting the power to considerable distances removes the need of locating the factory near the source of the water power (p. 441).

Influence of nearness to market. The advantages of a nearby market, or of superior facilities for shipping goods to more distant markets, have been leading factors in determining the location of many industries.

An interesting example is afforded by the location of the leading refineries handling imported cane-sugar. Sugar is refined and molasses is manufactured to some extent in Louisiana, where cane is grown. But much cane-sugar is imported, and the largest refineries are in New York and Philadelphia (p. 569), in part because of the heavy local consumption and the excellent means of distribution to outside markets. Furthermore, by having the refineries at tidewater the cost of transporting the raw material is reduced.

A more striking case is that of the manufacture of agricultural implements. The chief market for these things is in the leading farming sections. Many implements are very heavy and occupy much car-space, so that freight rates on them are high. For their manufacture, there is accordingly great advantage in a location near the chief market. As a result, there has been a steady westward migration of the industry as the great grain districts have expanded in that direction (p. 544). In 1880, Ohio and New York were leaders in the industry; now, Illinois is far ahead of both combined, its output having increased threefold in thirty years. In 1880, the value of the output in Springfield, Ohio, was double that of Chicago; now the latter has an output nearly five times greater than that of Springfield, which has remained nearly stationary.

Influence of supply of labor. The importance of a local supply of labor in determining the location of manufactures varies greatly. It depends in part on the character of the industry, being more important in the case of industries requiring skilled labor than in others. In general, it is much less important now than formerly, for it has become increasingly easy to bring laborers to any given point where other conditions are favorable. Doubtless, too, labor will be even more mobile in the future.

In the past, the development of manufactures in some of the southern states and in California has been retarded by lack of a satisfactory supply of labor. On the other hand, the leadership of New York City in the ready-made clothing industry is due in part to the presence of abundant cheap labor. The long-continued supremacy of New England in the manufacture of cotton has been maintained of late years largely through the possession of expert workers.

Other factors. In addition to the leading factors discussed above, there are various minor factors which may influence the

location of manufacturing industries. Thus the advantage of an early start has located certain industries in places without superior natural advantages. In most cases this advantage is associated closely with the question of labor.

The boot and shoe industry of Brockton, Lynn, and Haverhill, Massachusetts, illustrates the advantage of an early start. The industry was established in these places at an early date, and by enlisting the services of many of the people, a supply of skilled labor was developed with enough impetus to give first rank to the localities. Most of the shoe factories of these cities are run by steam power, developed from Pennsylvania coal, and most of the leather they use is tanned in other states. Clearly, their leadership rests on an insecure basis, and the business is growing fast in other cities having more fundamental advantages.

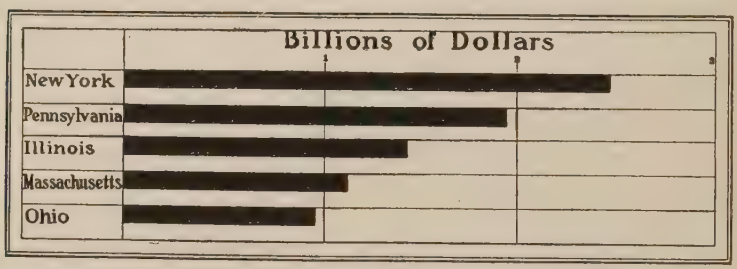

Fig. 435. Diagram showing value of manufactures by leading states (1905).

In earlier years, industries frequently were established in particular places because of a supply of local capital, but now such cases are relatively few and unimportant. Broadly speaking, capital is perfectly mobile, and goes wherever other conditions are favorable. Climate may also be a direct factor in determining the location of manufacturing industries, though its influence is offset easily by other considerations. Thus the climate of the northern states is more invigorating than that of the southern states, and workingmen are likely to render more efficient service, on the average, in the former than in the latter. Yet because of other advantages, the manufacturing industries of the South are growing rapidly.

Combined influence of various factors. While many industries are located largely or wholly by one or two factors, the distribution of others is the result of the combined influence of most or all of the things mentioned above. Many industries, too, have been located without regard to the geographic and economic conditions involved, and not a few have failed for this reason.

Further illustrations of the leading factors which influence the distribution of manufacturing industries occur in the following pages, in connection with the discussion of the leading manufactures of the country.

The leading manufacturing states and cities. New York, Pennsylvania, Illinois, Massachusetts, and Ohio, in this order, are the five leading manufacturing states (Fig. 435), while New York City, Chicago, Philadelphia, St. Louis, and Boston are the five most important manufacturing cities (Fig. 436). In 1905, the combined value of the manufactured products of cities having (in 1900) a population of 8,000 or more was more than twice that of smaller

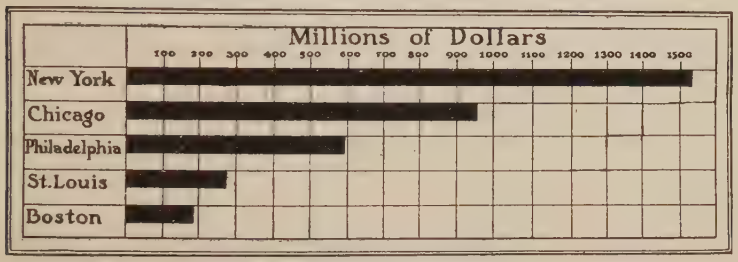

Fig. 436. Diagram showing value of manufactures by leading cities (1905).

cities and rural districts. The more rapid growth of urban as compared with rural population has been one of the most striking and significant things in connection with the population changes of recent years (p. 593). It has been due in large part to the rapid growth of urban industries. The factories in the territory east of the Mississippi River and north of the Ohio and Potomac rivers employ about ¾ of all the industrial wage-earners (not workers on farms) of the country, and contribute about the same proportion of the total value of manufactured products. (What are the general advantages which this section enjoys for manufacturing?)

Leading Manufactures of the United States

The Federal Census Bureau has divided the 339 classes of manufactures that are carried on in the United States into 14 groups. These are shown in the accompanying table.

MANUFACTURING INDUSTRIES OF THE UNITED STATES IN 1905

(Ranked according to value of product)

Group	Number of Establishments	Capital Invested	Wages Paid	Value of Products, Including Custom Work and Repairing
Food and kindred products	45,790	$1,173,151,276	$164,601,803	$2,845,234,900
Iron and steel and their products	14,239	2,331,498,157	482,357,503	2,176,739,726
Textiles	17,042	1,744,169,234	419,841,630	2,147,441,418
Lumber and its manufactures	32,726	1,013,827,138	336,058,173	1,223,730,336
Chemicals and allied products	9,680	1,504,728,510	93,965,248	1,031,965,263
Metals and metal products other than iron and steel	6,310	598,340,758	117,599,837	922,262,456
Paper and printing	30,787	798,758,312	185,547,791	857,112,256
Leather and its finished products	4,945	440,777,194	116,694,140	705,747,470
Vehicles for land transportation	7,285	447,697,020	221,860,517	643,924,442
Liquors and beverages	6,381	659,547,620	45,146,285	501,266,605
Clay, glass, and stone products	10,775	553,846,682	148,471,903	391,230,422
Tobacco	16,828	323,983,501	62,640,303	331,117,681
Shipbuilding	1,097	121,623,700	29,241,087	82,769,239
Miscellaneous industries	12,377	974,316,571	187,514,312	941,604,873
United States	216,262	12,686,265,673	2,611,540,532	14,802,147,087

Food and kindred products. The more important items in this group are slaughtering and meat-packing products; flour and grist-mill products; butter, cheese, and condensed milk; canned and preserved fruits, vegetables, and fish; and refined sugar (p. 571).

The slaughtering and meat-packing industry tends to keep close to the great stock-raising areas (pp. 553-555), in order to avoid freight charges on waste material and to prevent the animals losing weight on the way to the slaughtering centers. Grazing naturally precedes farming in the order of economic development (Why?), and as the chief grazing area moved westward in front of the advancing agricultural zone, the slaughtering and packing industry followed. In early days, stock was driven from the pastures of the

Piedmont Plateau to be killed at Philadelphia, Baltimore, and Charleston. The battle of Cowpens, in the Revolutionary War, was so called because fought about the pens of a Piedmont cattle ranch. Later, great numbers of cattle and hogs were driven to the seaboard from the settlements west of the Appalachians (p. 419). After the War of 1812, the pork-packing industry found its chief center in Cincinnati, where it remained until about 1860 (p. 422). During this period, the business was carried on also at various other points on the Ohio canals and the Ohio, Mississippi, Illinois, Wabash, and other rivers. By 1861–1862, the center of the industry had moved from Cincinnati to Chicago, and the business had declined in many of the river towns. Greater economy in manufacture was possible in a small number of large establishments than in a large number of small ones, and Chicago, as the greatest railroad center, had unrivalled facilities for assembling the stock. It is also on the northern edge of the corn belt (Fig. 409; Why important?), and within easy reach of the great grazing lands. Chicago still leads in the industry, contributing nearly ⅓ of the total value of the products for the country, but the second and third centers are found on the Missouri River, at Kansas City and South Omaha, respectively. Apart from its westward migration and its tendency toward concentration at a few favored points, the most important thing in the later history of this industry has been the more and more nearly complete use of the waste products of the slaughter houses. Among the things made from these products are soap, candles, glue, gelatine, glycerine, ammonia, knife-handles, and fertilizer. The total value of the products of the industry in 1905 was $914,000,000.

The value of the flour and grist mill products of the United States has increased rapidly with the growth in the production of cereals, and now amounts to more than $700,000,000 yearly. Two-thirds of the value of the output of these mills is in wheat flour. Other important products are rye and buckwheat flour, corn meal, and feed for animals. All branches of the industry have expanded toward the West, following the westward movement of the centers of production of the great cereal crops (Fig. 412). Flour and grist mills are distributed widely, for with the exception of a comparatively few large mills, they supply local demands only. Minnesota, New York, Kansas, Ohio, and Illinois are the leading flour-producing states, and Minneapolis is the most important city in the world in this industry (p. 441).

The manufacture of dairy products in factories is a modern development. Formerly, this work was done almost entirely on the farms. In 1851, for example, there was only one cheese factory in the United States; in 1905, there were more than 3,600. New York, Wisconsin, Iowa, Illinois, Minnesota, and Pennsylvania are the six leading states in the industry (p. 568). The annual value of factory-made butter, cheese, and condensed milk is about $170,000,000.

The canning and preserving of foods is a comparatively new industry in the United States, having little importance before 1850. Now, the total yearly value of canned foods, exclusive of meats, is about $100,000,000. The leading states in the industry are California, Maryland, and New York. The conditions which determine the distribution of the industry have been given (p. 567). The canning and preserving of fruits and vegetables are largely the outcome of climatic conditions. Many fruits and vegetables are naturally available during only a small part of the year, and can be grown only in certain places. The canning and preserving industry makes them available out of season, and in all parts of the country.

Iron and steel and their products. This group of manufactures ranks second in value of product (p. 574). It comprises 37 industries, the basic ones being the manufacture of iron and steel. Among the others are those producing structural iron work, rails, machinery, tools, hardware, tin plate (really sheets of iron coated with tin), and various small products. Although the iron and steel industry is carried on in some 27 states, nearly 9/10 of the total output comes from Pennsylvania, Ohio, Illinois, and Alabama.

The successful use of hard coal as fuel gave the first great impulse to iron production, and located the iron industry in eastern Pennsylvania, with Philadelphia the leading market. About the close of the Civil War, the center of the industry moved to Pittsburgh, where it still remains. A number of influences led to the change: (1) The hard coal of eastern Pennsylvania, because less abundant and in great demand for domestic use, cost more than the soft coal of the western part of the state. Furthermore, coke made from the latter was more efficient, ton for ton, than hard coal. (2) The Lake Superior ore was of high average grade, was mined easily, and could be brought to Lake Erie ports cheaply by lake. (3) The rapid development of the country west of the Appalachians helped to

bring about the change. Although Pittsburgh did not become the center of the industry until after the Civil War, it had nail factories, foundries, and the like, before the beginning of the century. As early as 1815 or 1820 it was dubbed the "Birmingham of America" and the "Young Manchester," because it was already black with smoke from its factories. As indicated elsewhere (p. 431; Fig. 315), Lake Superior iron ore goes to Pennsylvania coal, rather than the reverse, because much more coal than ore is needed in the manufacture of steel, and because the ore, in being sent to Pittsburgh, is on the way to its final market. Various phases of the iron industry are carried on less extensively at other cities on or near the Great Lakes, especially at Chicago and Cleveland, where ore and coal can be brought together cheaply, and where market conditions are good.

In the South, Birmingham, Alabama, is the leading center of the iron and steel industry. In smelting iron ore it is mixed with limestone and coke, and when the mixture is heated in the furnace, the metal iron is released from the ore, and is drawn out into molds. At Birmingham, iron ore, coal, and limestone are found close together. This fortunate combination (with the Southern market) has made Birmingham an important city, and a leading factor in the industrial growth of the southern states.

Textile manufactures. The industries of this group furnish the materials for nearly all our clothing and for many household articles, such as rugs and carpets, draperies, and bedding. Vegetable and animal fibers constitute the raw materials used by the 44 textile industries. The principal industries of the group are based on cotton, wool, and silk. Various products are made also from flax, hemp, and jute.

The textile mills of the United States consumed in 1905 nearly 2,000,000,000 pounds of raw cotton, valued at more than $234,000,000. The value of the cotton manufactures was more than $450,000,000. Southern New England has led in the manufacture of cotton throughout the history of the industry in the United States, but now its leadership is threatened seriously by the South Atlantic states. The rate at which the industry is migrating to the latter section is suggested by the accompanying table, which shows that in recent years both the actual and proportional increase in employees, spindles operated, and raw cotton consumed has been much greater in the South Atlantic states than in New England. New England has the advantage of a much earlier start in the industry, and of a better supply of labor (p. 571); but the southern mills are very much nearer the cotton fields. Both sections possess abundant water power. This is a minor factor in New England, but a very important one in the South.

STATISTICS OF COTTON TEXTILE INDUSTRY

Year	Employees		Spindles		Raw Cotton Consumed (Bales)	
	New England	South Atlantic	New England	South Atlantic	New England	South Atlantic
1880	125,779	16,317	.....	.....	.....	.....
1900	162,294	97,494	12,850,987	4,298,188	1,719,622	1,477,775
1905	155,981	120,110	13,911,241	7,508,749	1,558,094	1,813,659

Woolen manufactures include worsted goods, suiting, blankets, carpets, felt goods, and wool hats. Much wool is imported for the mills, which consume more than 500,000,000 pounds annually. The leading manufacturing centers are the Middle Atlantic and New England states. The output of machine-made hosiery and knit goods (chiefly underwear) has increased rapidly during recent years. Philadelphia leads in the manufacture of hosiery and knit goods, with Utica, New York, second.

The silk mills of the United States are dependent entirely upon foreign countries for raw material. Mulberry trees could be grown and silkworms reared in this country, but the industry requires much hand labor, and the cost of the latter in the United States prevents the production of raw silk in competition with southern Europe, Japan, and China. The leading silk-manufacturing states are New Jersey, Pennsylvania, New York, and Connecticut, with Paterson, New Jersey, the leading city.

Lumber and its manufactures. The logging-camp and lumber-mill furnish material for the 23 other branches of industry included in this group. The fundamental industries have been discussed (pp. 556-559). Among the products of the industries which use lumber are doors, blinds, sash, interior finish, boxes, matches, "woodenware," and furniture (p. 568). Great quantities of lumber are used also in building, and in certain industries included in other groups, such as ship building and the manufacture of carriages and wagons. Lumber products are manufactured on a commercial scale in every state, in marked contrast with the concentration of certain of the other greater industries, such as the manufacture of iron and steel and textiles.

There is an enormous loss of material in the wood-working industries, mainly in the form of sawdust, shavings, and small blocks. It is estimated, for example, that in the furniture industry the loss in seasoning and factory amounts to 25 per cent; in making boxes, to about 20 per cent; and in the manufacture of vehicles and farming implements, to about 25 per cent. The total estimated loss in adapting lumber to its final use in 1907 was 6,803,000,000 feet, board measure. While the loss can be reduced greatly by better methods and greater care, it can never be avoided entirely. In the future, however, such refuse material, together with that of the logging-camp (tops, stumps, butts, etc.) and lumber-mill

(slabs, edgings, trimmings, etc.), probably will be used more and more for the manufacture of various by-products. Among the possible by-products are turpentine, from the refuse of Southern pine; tannic acid (p. 580), from refuse chestnut wood; wood-pulp; and several chemical products. Various by-products are made now from refuse wood in some foreign countries, though little has been done along this line in the United States, because until recently wood has been both abundant and cheap. It has become clear, however, that this is a matter of great importance in conserving our forest resources, and the Forest Service is making an exhaustive study of the possibilities of using wood refuse.

Chemicals and allied products. This group contains many manufactures which serve a wide variety of purposes. Among the products are paints and varnishes, dyestuffs, bleaching materials, medicines, druggists' preparations, baking powder, glue, soap, ink, various oils, explosives, and fertilizers. Naturally, such diverse commodities are manufactured in many different places, but more than half the products of the group as a whole come from Pennsylvania, New York, New Jersey, Ohio, and Illinois.

Metals and metal products other than iron and steel. Many things are made of gold, silver, copper, lead, and zinc (pp. 286-287), such as jewelry, watches, clocks, silverware, brassware, and pins. Many of the 34 classes of industry belonging to this group are carried on extensively in the northeastern states, especially southern New England. The chief advantages enjoyed by this section in these industries are (1) an early start, and (2) the services of skilled workers, more numerous there than elsewhere during the early development of these industries.

Paper and printing. Printing and publishing are the most important and most widely distributed industries of this group, which includes also the manufacture of wood-pulp, paper of all kinds, paper bags and boxes, etc.

The principal centers of the wood-pulp industry have been noted (p. 441). The output of paper boxes has increased rapidly during recent years; largely because of the increasing cost of wood, many commodities are now put up in paper boxes which formerly were packed in wooden boxes. The annual per capita value of the output in the printing and publishing business is more than ten times greater than it was in 1850. This significant change reflects in part the progress made in education, the reduced cost of reading matter, and the greater facilities for its distribution, such as rural free delivery. In 1905, the value of the products of printing and publishing in six states — New York, Illinois, Pennsylvania, Massachusetts, Ohio, and Missouri — amounted to ⅔ that for the entire country.

Leather and its finished products. The basic industry in this group is tanning, while the dependent industries include the manu-

facture of leather products of all kinds. Of the latter, the boot and shoe industry is most important, but large quantities of leather are used in making harnesses, saddles, trunks, bags, furniture, gloves, mittens, and belting, in binding books, and in other ways. For many years Massachusetts has been the leading shoe-manufacturing state (p. 572), but the industry is growing rapidly at various points in the middle states.

In the past, the tanning industry has depended chiefly on local supplies of tannic acid, obtained usually from the bark of oak or hemlock, and as the supply of bark failed in one area, the industry developed in another. Massachusetts, the seat of the first tannery, reached its greatest importance in the industry in 1880, when it furnished about 1/6 of the total output for the country. Now it furnishes hardly 1/8. The industry culminated in New York in the seventies. Pennsylvania took the lead when the production of New York declined, and still holds first rank. Later, the industry became important farther west, especially in Michigan and Wisconsin. Until recently, the industry was attended by an enormous waste of timber; trees were felled by thousands, from which only the bark was taken for the tanneries, the logs being left to rot in the woods.

Vehicles for land transportation. The operations of the repair shops of steam railroad companies, the manufacture of carriages and wagons, and the manufacture of steam railroad cars are the most important of the 11 industries comprising this group. In recent years the output of bicycles has declined rapidly, while that of automobiles and motorcycles has increased enormously.

The value of the automobiles made in 1900 was less than $5,000,000; in 1905, about $27,000,000. In 1905, automobiles were manufactured in 17 states, with Michigan, Ohio, New York, and Connecticut leading. The value of those made in Detroit was more than 1/5 of the total for the industry. The leadership of Detroit appears to be due to the impetus resulting from the success of the first factories established, rather than to superior natural advantages. Many factories now make a specialty of certain parts of the automobile, such as bodies, motors, lamps, and tires.

Liquors and beverages. The value of these products increased nearly 1/3 between 1900 and 1905, amounting to more than $440,000,000 in the latter year. Illinois leads the states in making distilled liquors, while Indiana, Ohio, and Kentucky follow in the order named. New York, Pennsylvania, Wisconsin, Missouri, and Illinois are the leading states in the production of malt liquors. California, New York, and Ohio lead in making wine.

Peoria, Illinois, ranks first among American cities in the manufacture of distilled liquors. In 1905, the value of the Peoria products exceeded $42,000,000. This formed nearly 78 per cent of the total for the industry in the state, and repre-

sented an increase in value of more than 57 per cent in five years. It formed, furthermore, more than 69 per cent of the combined value of the products of all Peoria industries. Peoria was led to specialize to such an extent in the liquor industry, and attained leadership in it, largely because of (1) its central location in the corn belt of the state; (2) its transportation facilities, which enable it to collect at low freight rates the surplus grain of the surrounding area; and (3) an abundant supply of cheap coal from nearby mines. The importance of Peoria's favorable position in the Illinois corn belt is suggested by the fact that the distilleries of the city used 5,809,170 bushels of corn during a recent year. This meant the yield from 464 acres of corn each week day of the year (counting 40 bushels to the acre). The manufactured product, owing to its relatively small bulk and large value, can bear the cost of transportation to distant markets. Nearness to the grain supply has also been an important factor in the manufacture of malt liquor in Milwaukee, Chicago, St. Louis, Cincinnati, and St. Paul.

Clay, glass, and stone products. Some of the industries of this group have been noted sufficiently in earlier connections (pp. 278-280, 407). Clay products are used most in the building trades, and their consumption is increasing rapidly. Ohio, Pennsylvania, New Jersey, Illinois, and New York lead in clay products. Pennsylvania, Indiana, and Ohio lead in the manufacture of glass.

Deposits of quartz sand, the only raw material which enters into all kinds of glass, occur in many parts of the country, but the manufacture of glass on a large scale is fairly well localized because of the need of satisfactory fuel for the work. With good fuel, a skillful glass-maker can make fairly good glass from inferior material, but with poor fuel he cannot make good glass with the best materials. Gas is the ideal fuel in glass-making, because it is cleanest, and gives intense, uniform heat under perfect control. The leading states in the industry attained that position largely because of their supplies of natural gas.

Tobacco products. These include cigars, cigarettes, chewing and smoking tobacco, and snuff. The value of the products increased from $31,000,000 in 1860 to $331,000,000 in 1905. The manufacture of cigars is distributed widely, Pennsylvania, New York, and Ohio leading. More than ⅘ of the total output of cigarettes are made in New York and Virginia. Missouri, North Carolina, Kentucky, and Virginia lead in the production of chewing and smoking tobacco.

Shipbuilding. Since 1850, the value of the products of this industry has increased nearly fourfold and the capital invested twenty-one fold. The latter fact means that, as iron and steel steamships replaced wooden sailing vessels, much more capital was required than when ships were built of wood only. The need of greater capital helped to bring about the concentration of shipbuilding in large

establishments, with the result that there were only about half as many establishments in 1905 as in 1880.

In 1905, the capital invested in the iron and steel branch of the industry was more than 4/5 of the total capital invested in shipbuilding. Furthermore, the increase in the former between 1900 and 1905 was more than double the total amount invested in wooden shipbuilding in the latter year.

New York, Pennsylvania, Virginia, New Jersey, and Massachusetts are the leading shipbuilding states on the Atlantic coast; Ohio and Michigan lead on the Great Lakes; and California and Washington on the Pacific coast.

The rapid growth in recent years of the shipbuilding industry on the Great Lakes has been due to the demand created by the enormous increase in the commerce of the lakes (pp. 427, 430). At the same time, of course, the development of shipbuilding has favored the continued growth of lake transportation. The shipyards at West Bay City, Michigan, and West Superior, Wisconsin, are outgrowths of the wooden shipbuilding industry. Those at or near Buffalo, Lorain, Cleveland, Toledo, Detroit, and South Chicago are located conveniently with reference to the great steel mills.

Miscellaneous industries. There are 65 industries of varying importance carried on in the United States which cannot be classed properly with any of the other groups. The combined value of their products in 1905 was more than $941,000,000. Among the industries of the group whose products are of greater value are the manufacture of agricultural implements (p. 571); ammunition; brooms and brushes; buttons; coke (p. 576); electrical machinery, apparatus, and supplies; fur goods; ice; mattresses and spring-beds; musical instruments; photographic materials and apparatus, and rubber and elastic goods.

Questions

1. (1) Explain the fact that the shores of Chesapeake Bay, Long Island, and Lake Michigan (east shore) were among the first sections to grow vegetables on a large scale for city markets. (2) Why was the business more important on the *east* shore of Lake Michigan than on the *west* shore?

2. Formerly strawberries were grown extensively in a few places only, as in parts of Maryland, New York, Ohio, and western Michigan. Now they are grown on a large scale in Florida, Tennessee, Arkansas, Missouri, and other states. (1) Explain the relatively early development of the business in the first-mentioned states. (2) What permitted its later development in the other states?

3. Name several crops not mentioned in the text which are cultivated widely in the United States, and several which are grown in a few places only. Explain the facts involved in each case.

4. Why was the original stand of timber in the Pacific Forest (Fig. 428) approximately equal in amount to that in the eastern Hardwood Forest, although the area of the former was less than ⅓ that of the latter?

5. It is estimated that the forests of the United States (Fig. 428) contain about the following percentages of their original stand of timber: Northern Forest, 30 per cent; Hardwood Forest, 21 per cent; Southern Forest, 50 per cent; Rocky Mountain Forest, 75 per cent; Pacific Forest, 79 per cent. Why the differences?

6. What advantages have made New Jersey a great manufacturing state, in spite of the fact that it has small fuel and water-power resources, and produces relatively little of the raw material used by its factories?

7. Why is manufacturing relatively unimportant in North Dakota and South Dakota?

8. Explain the fact that in Nebraska most of the manufacturing is done in the eastern part of the state (more than 4/5 of it in two counties), while in Iowa it is distributed rather evenly throughout the state.

9. (1) Name several industries not discussed in the text, the distribution of which is influenced to an important degree by nearness to raw material. (2) Name several influenced by nearness to market.

10. Among the leading manufactures of Chicago are meat products, men's clothing, foundry and machine shop products, iron and steel, the products of printing and publishing houses, and railroad cars. What advantages has Chicago for carrying on each of these industries?

11. Compare and contrast the general advantages for manufacturing of (1) Massachusetts and Texas, and (2) Utah and Ohio.

12. Flour and sugar are household necessities. (1) Explain why the former is made in thousands of mills throughout the country, and the latter at comparatively few points. (2) Will the situation with regard to sugar change in the future? Why?

13. Why does West Virginia rank low (29th) as a manufacturing state, although it mines much coal (second coal-producing state in 1910)?

14. Explain the fact that Pennsylvania, Illinois, West Virginia, and Ohio have produced about ¾ of all the coal mined in the United States.

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CHAPTER XXI

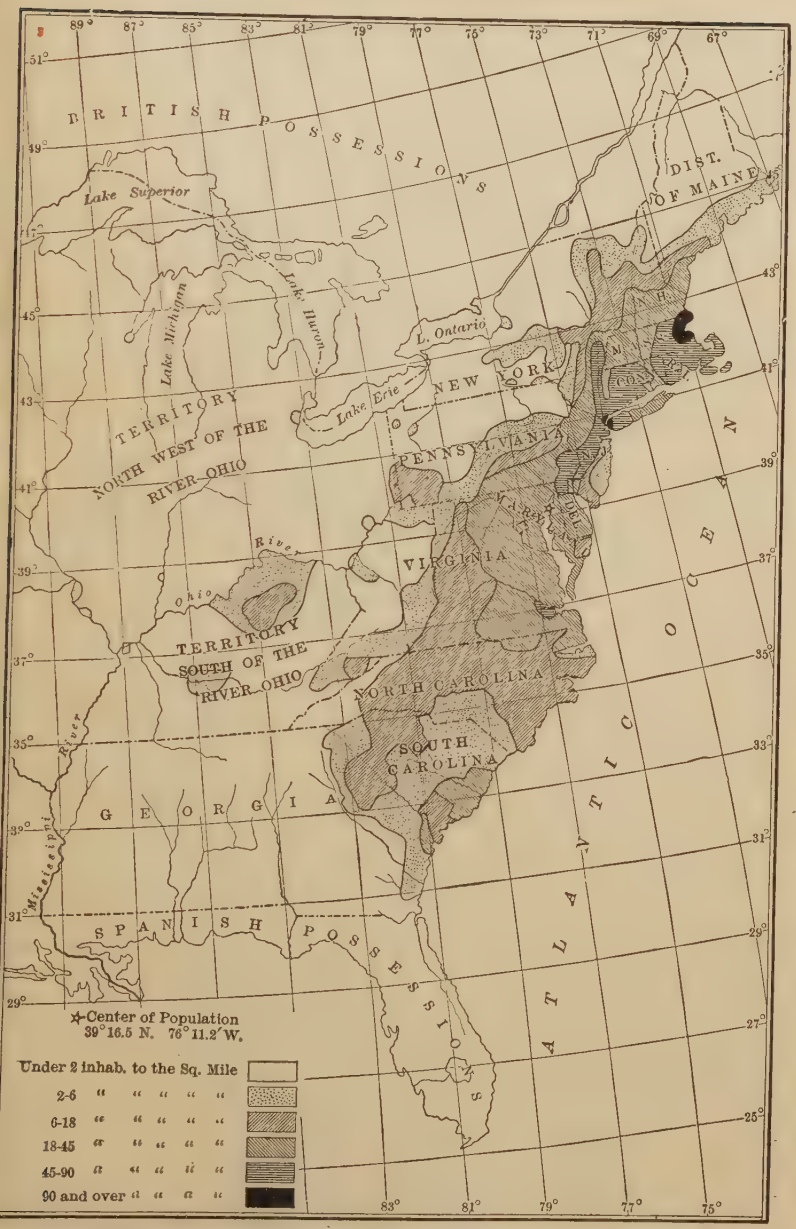
DISTRIBUTION OF POPULATION; DEVELOPMENT OF CITIES

Factors Affecting Density

As preceding discussions have shown, the distribution and density of population are influenced by many factors—such as topography, climate, soil, natural resources, transportation facilities, and the occupations of the people. The influence of these factors may be reviewed by considering briefly the expansion and present distribution of population in the United States.

Fig. 437 shows the distribution of population in 1790, when the first census was taken. The great majority of the people, emigrants from Europe, were still east of the Appalachian Mountains. This was due largely to the difficulty of crossing the mountain barrier, the privations, dangers, and difficulties of life in the Interior, and the desirability of being near the Atlantic Ocean or some navigable river flowing into it, for purposes of trade. Furthermore, the lands east of the mountains and along the Great Appalachian Valley had been sufficient for the needs of the settlers until a few years before (about 1775). The settled area was widest at the south, where the combined width of the Coastal Plain and Piedmont Plateau is greatest.

In New England, the population was densest toward the south and southeast. This is explained by the more rigorous climate at the north; the rough uplands, infertile in many places; the fact that few of the rivers served as effective highways into the interior (Why?); and the dominance of sea-interests (fishing, shipbuilding, the carrying trade) in New England life. The influence of the Connecticut Valley and the Champlain lowland on the distribution of the frontier population is interesting. In New York, population was confined mainly to the vicinity of the Hudson and Mohawk valleys, which had fertile soils in many places, and afforded easy communication with New York City. The Adirondacks and Catskills were almost uninhabited. The sandy, forested coastal plain of southeastern New Jersey had a sparse population, while a strip of denser settlement extended across the state between Philadelphia and New York City. (Why? Compare with Figs. 439 and 441.) In the Carolinas the Piedmont Plateau, with its relatively small farms, had a denser population than parts of the Coastal Plain, with its big plantations. The influence of the Great Appalachian Valley is shown


BRITISH POSSESSIONS
DIST. OF MAINE
Lake Superior
Lake Michigan
Lake Huron
L. Ontario
Lake Erie
NEW YORK
TERRITORY NORTH WEST OF THE RIVER OHIO
PENNSYLVANIA
VIRGINIA
TERRITORY SOUTH OF THE RIVER OHIO
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
Mississippi River
SPANISH POSSESSIONS
ATLANTIC OCEAN
Center of Population
39°16.5 N. 76°11.2′ W.
Under 2 inhab. to the Sq. Mile
2-6 " " " " "
6-18 " " " " "
18-45 " " " " "
45-90 " " " " "
90 and over " " " "

by the peninsula of settlement which extended southwest from Virginia. The settled area in southwestern Pennsylvania reflects, in part, the attractions of the Monongahela Valley and some of its tributaries. It was reached by several routes leading through the mountains, of which the one that followed the Potomac River and Wills Creek Water-Gap (p. 359) was most important. The large island of settlement in north-central Kentucky coincided with the famous "Blue Grass Region." Here were rich soils formed from limestones and limey-shales, numerous salt springs (p. 288), and navigable streams. The settlers of central Tennessee were also in a region of fertile limestone soils, and used the Cumberland River as a highway. The rough plateau lands of eastern Tennessee, Kentucky, and West Virginia had few settlers, or none at all.

After 1790 population spread rapidly toward the west (Fig. 438), especially along such highways as the Ohio River and (later) the Great Lakes (p. 428). The population map for 1820 (Fig. 439)

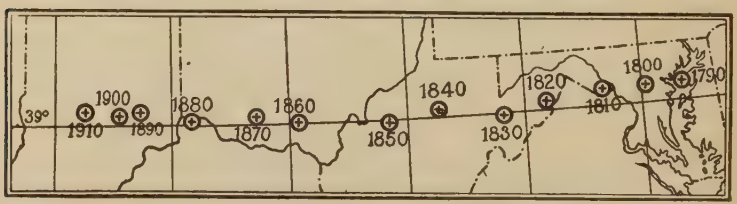


Fig. 438. Map showing the center of population in the United States at each census, 1790 to 1910.

shows strikingly the influence of geographic features. The Adirondack Mountains and the less accessible portions of the Appalachian Mountains and the Alleghany Plateau remained uninhabited wildernesses. On the other hand, most of the fertile lowlands favorably situated and available for settlement had been occupied. The most striking characteristic of the western frontier was the control of settlement by the larger rivers, which were the principal highways of the time (pp. 419-422). Each one (the Red, Washita, Arkansas, Missouri, Mississippi, and others) was bordered for some distance by a narrow settled area, while the interstream tracts were still unoccupied. The influence of lines of approach from the East is illustrated by the belt of settlement extending from western New York around the southern shore of Lake Erie to Lake St. Clair. The presence of Indians accounts for some of the blank areas on the map, within the generally settled region, as in Georgia, Alabama, central and northern Mississippi, and western Tennessee. After the removal of the Indians, these areas were settled quickly.

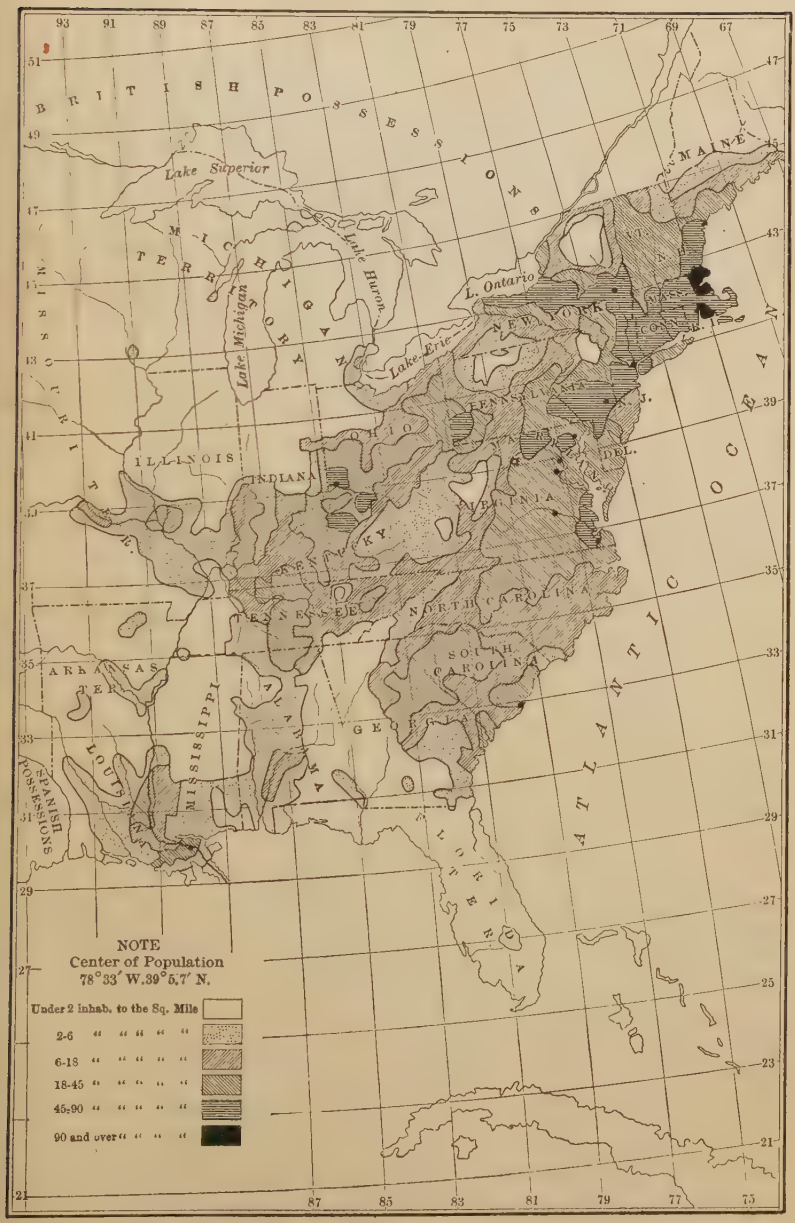


Fig. 439. Map showing distribution of population in the United States in 1820.

The unsettled condition of northwestern Ohio was due partly to the "Great Black Swamp." The lower part of the Mississippi delta and some of the lands along the Gulf coast also were unoccupied because swampy. Even now, some of these areas are uninhabited, while others recently have been made available for settlement by drainage (p. 459). For some years, settlers avoided the prairies of the northern Interior. They were thought infertile (p. 276); timber was imperatively needed for buildings, fences, and fuel; they did not afford an adequate supply of running water for stock or mills; there was little protection from the bitter winds of winter; and the farmers did not know how to "break" and work the tough prairie sod. The gradual conquest of the prairies is one of the most interesting phases of the settlement of the region. The dense forests in the northern parts of the Lake states helped for a long time to keep agricultural settlers away from large areas.

The appearance of the railroad introduced a new and powerful factor in the expansion of population. The first American railroad was built in Massachusetts in 1826. By the early 1850's, railroads had been constructed across the Appalachian Mountains from the leading seaports of the Northeast. In 1853 Chicago was connected by rail with New York City. The Mississippi River was reached shortly after, and in 1869 the first transcontinental railroad was completed. The extension of railroads opened up vast areas for settlement which had not been available before. This was particularly true of large areas west of the Mississippi, whose settlement and development, in the absence of navigable waterways, had to await the railroad. Fig. 440 shows the present railroad web.

By 1880, many parts of the West were settled (Fig. 441). Fertile soils had favored farming along the bases of some of the mountains and in many valleys, the discovery of important mineral deposits had attracted thousands of prospectors and miners to various places, and the grazing industry supported a sparse population over wide areas.

The settlements in the Black Hills (southwestern South Dakota) were the result of the recent discovery there of gold. Most of the settlers in central and western Montana were farmers, located chiefly in the valleys of the principal streams. Besides the farmers, there were some miners. In Colorado there were agricultural settlements (1) along the east base of the Rocky Mountains, where, at many points, conditions were favorable for irrigation, and (2) in some of the mountain valleys. In addition, a large mining population had been attracted to the state by the discovery, a few years before, of rich and extensive deposits of gold, silver, and lead in the Leadville district (p. 479). In New Mexico, the Rio Grande, Rio Pecos, and upper Canadian valleys had drawn many settlers. In Utah, the agricultural settlements of the Mormons were spread along the base of the Wasatch Mountains, where there were fertile and irrigable soils (p. 445). The principal agricultural settlements in Nevada were in the Humboldt Valley

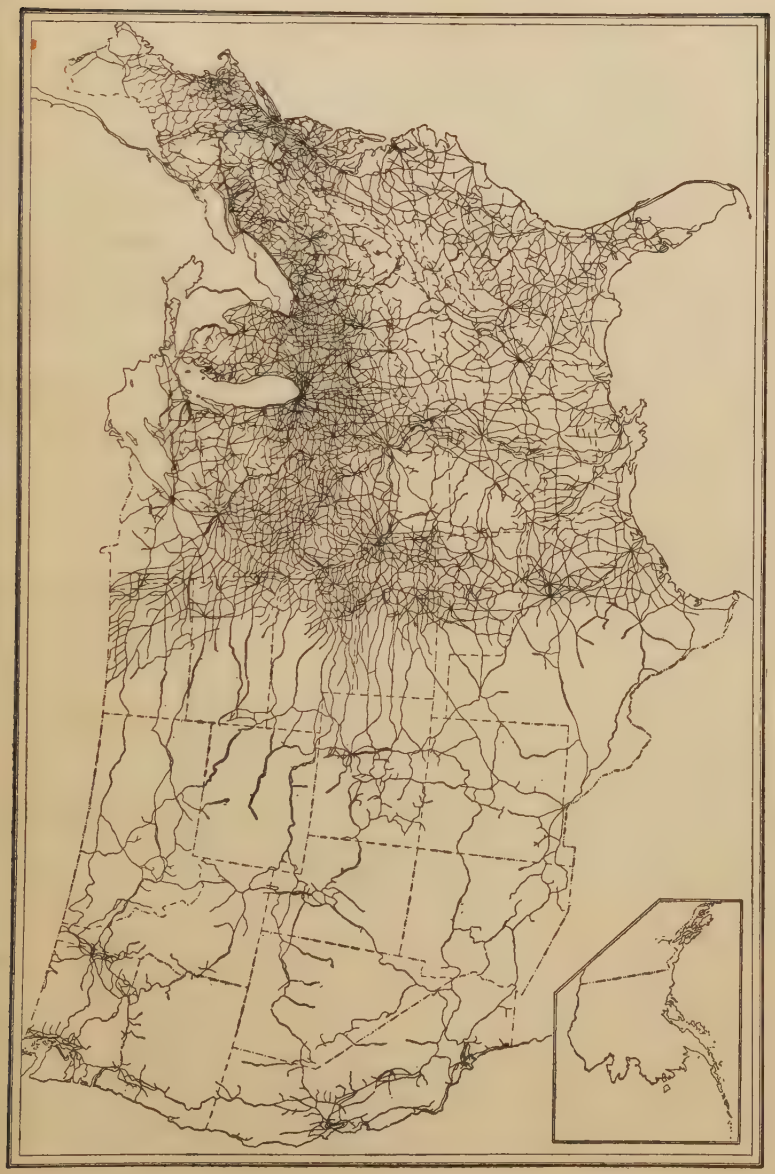


Fig. 440. The railroads of the United States in 1911.

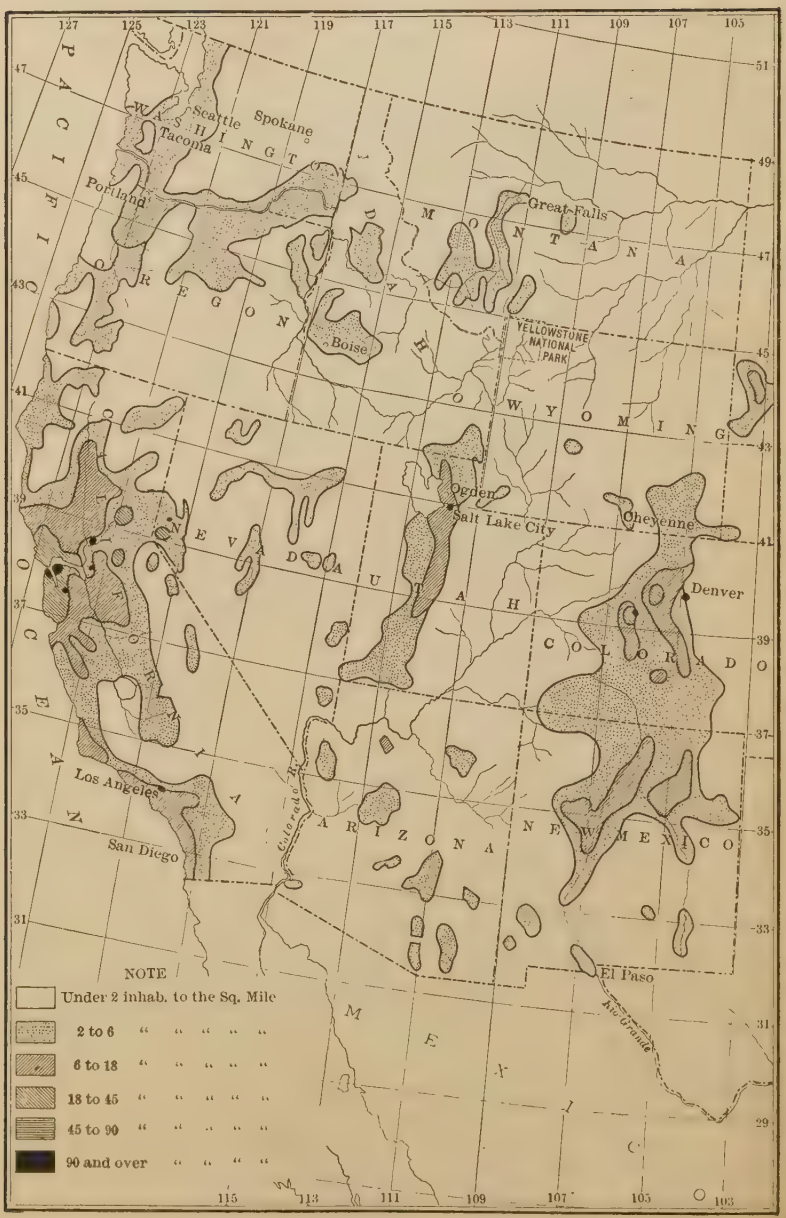


Fig. 441. Map showing distribution of population in the West in 1880.

and along the Central Pacific Railroad. The other settlements of the state depended chiefly on mining. In California, the commercial advantages of San Francisco Bay had attracted a relatively dense population, and some of the gold-producing districts were well settled. The great central valley and the more inviting valleys of the Coast Range were occupied by farmers.

The lowlands west of the Cascade Mountains in Oregon and Washington were occupied for the most part, while in the drier regions east of those mountains most of the settlements were confined to the vicinity of the Columbia River and its tributaries. The remaining population of the West was scattered widely at military posts, mining camps, and on cattle ranches.

The population map for 1900 (Fig. 442) will be interpreted readily in the light of the preceding discussion, and only its larger features need be noted here. The population of the eastern half of the country (east of the 96th meridian) was seven times as great as that of the western half. The relatively sparse population of the western half was due chiefly to prevailing aridity and the great extent of mountains and plateaus. Furthermore, many of the settled areas were occupied only recently. The relation of precipitation to population is suggested by the fact that only about 1/30 of the people were in regions where precipitation is less than 20 inches. Similarly, the relation of altitude to population is shown by the fact that more than 95 per cent of the population lived at elevations of less than 2,000 feet (p. 490). Since 1900, the population of many parts of the West has grown rapidly (Fig. 443) because of the development of irrigation, dry-farming, and mining, and the growth of commercial and industrial centers. The greatest densities (Fig. 442) are found in the northeastern quarter of the country. This region includes much of the glaciated area, with its highly productive soils; is unrivalled in its transportation facilities (Fig. 440); possesses vast resources in timber, in iron, coal, copper, and other useful minerals; and contains most of the great commercial and industrial centers of the country.

Cities

Cities have increased rapidly in the United States, both in number and size. In 1850, 12.5 per cent of the total population of the country lived in the 85 cities which had 8,000 or more people each; by 1900 the percentage of the population living in such cities had increased to 32.4 and the number of such cities to 517 (Fig. 444). Nearly half (46 per cent) of the people of the country now live in villages and cities exceeding 2,500 inhabitants. The increasing

Fig. 442. Map showing distribution of population in the United States in 1900.

concentration of population in cities has been due chiefly to the growth of urban commerce and industries (p. 573). The region of most pronounced urban development is east of the Missouri River, and north of the Ohio and Potomac rivers. Here are 35 of the 50 cities which, in 1910, had a population greater than 100,000.

The principal types of cities are (1) commercial cities, (2) manufacturing cities, (3) mining cities, (4) political centers, and (5) health

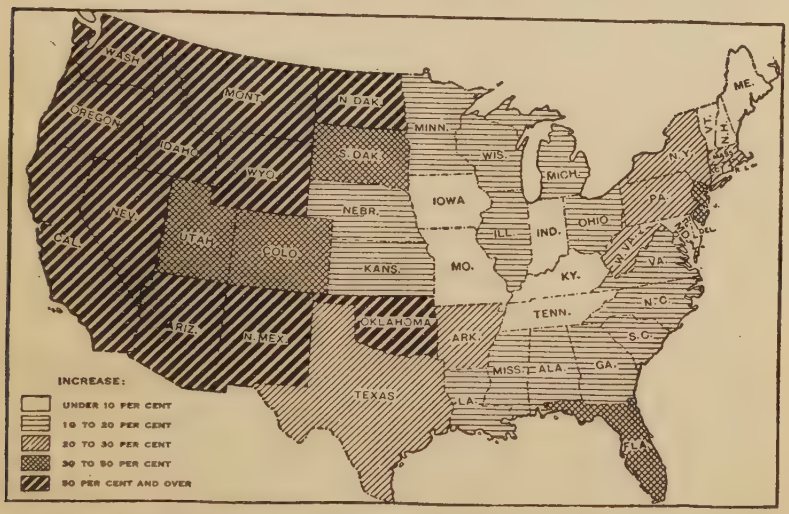


Fig. 443. Map classifying the states with respect to the percentage of increase of population, 1900 to 1910. (Bureau of the Census.)

or pleasure resorts. Most large cities are both commercial and industrial centers, while some belong also in varying degree to one or more of the other classes.

Commercial cities. Cities dependent chiefly on commerce grow up (1) where conditions favor the collection and distribution of commodities on a large scale, or (2) on important lines of communication at points where the mode of transportation is changed. Such places are (1) seaports, (2) river ports, (3) lake ports, and (4) railroad centers. (1) The growth of seaport cities is influenced mainly by (a) their position in relation to great trade routes; (b) the size, resources, population, and accessibility of their tributary areas (*hinterlands*), and (c) the character of their harbors. The ideal harbor is large

enough to afford anchorage for many boats, deep enough to admit the largest ships, protected from storms, free from ice, connected with the open sea by a deep channel, and has shores of such a character as to facilitate the construction of docks and the handling of freight (p. 525). Commercial cities are likely to grow up at or near the mouths of navigable rivers, for the latter serve as natural highways into the interior, and in many cases afford good harbors. When the lower courses of rivers are drowned, and so have deep channels,

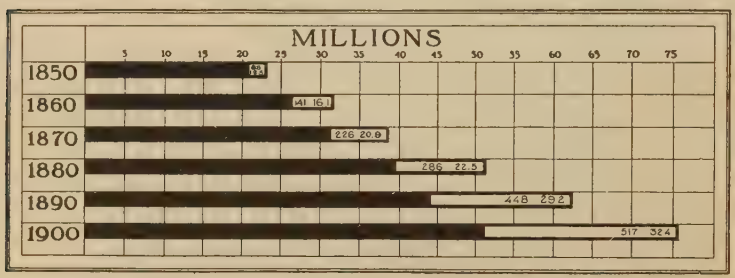


Fig. 444. Diagram showing the relation of rural and urban population in each census year, 1850 to 1900. The rural population is represented by the parts of the horizontal lines which are in solid black, while the urban population (in cities of 8,000 or more people) is shown at the right, where the first number indicates the number of cities having 8,000 or more people and the second number shows what proportion their aggregate population made of the total population.

such cities may be situated some distance up-stream, nearer the heart of the country. Thus Philadelphia and Baltimore, though more than 100 miles from the ocean, and Montreal, more than 800 miles inland, are, in effect, seaports.

San Francisco has an excellent harbor (Fig. 382), but trade with countries across the Pacific has been relatively unimportant; high mountains separate it from the interior, tending to restrict its hinterland and to handicap its trade by heavy freight rates; and to the east of these mountains stretch broad deserts with sparse populations. For years Boston, Philadelphia, and Baltimore, having good harbors and local hinterlands of importance, rivalled New York City in commercial importance. But the Hudson-Mohawk depression gave New York the best connections with the interior, and the opening of the Erie Canal (p. 434) added the Great Lakes Region to its hinterland, enabling it to leave its competitors behind.

(2) Since water transportation preceded railway transportation, most early inland cities are located at strategic points on navigable waterways. (a) At the head of river navigation goods are trans-

ferred from water to land, or vice versa, for further distribution, and hence commercial towns develop. Thus Haverhill grew up at the head of navigation on the Merrimac, Hartford on the Connecticut, Albany on the Hudson, Augusta on the Savannah, and St. Paul on the Mississippi. (b) River cities are found also at the junctions of large rivers, for such places are focal points for trade. Here traffic coming up-stream is divided, a part going up each stream, while in many cases commodities descending the tributary streams are transferred to boats operating on the main river. Pittsburgh (p. 422), Cairo, St. Louis (p. 423), and Vicksburg are examples of places whose earlier growth, at least, was stimulated by their position near the confluence of important streams. (c) A decided change in the direction of a river's course means a division of traffic and a change in the mode of carriage (Why?). Cincinnati (p. 422), Nashville, and Kansas City are conspicuous examples of American cities that have benefited from their positions on great bends of rivers. Kalamazoo, Michigan, and South Bend, Indiana, are types of many smaller places situated similarly. (d) Falls or rapids may give rise to a commercial city, for river freight must be unloaded, carried around the obstruction, and either reloaded or forwarded by land. The falls (rapids) of the Ohio made Louisville, those of St. Mary's River gave rise to Sault Ste. Marie, and the growth of Buffalo was aided by the falls and rapids of the Niagara.

(3) All the more important cities ranged along the Great Lakes started as commercial towns — as centers of exchange and transfer — and their commercial activities still dominate. As noted elsewhere (p. 427), their immediate location was determined in most cases by natural lines of communication leading from the shores of the lakes. It is interesting to note that the trade which contributed chiefly to the growth of most of the Great Lakes cities has been in one or two classes of goods. Duluth, Marquette, Ashland, and several other Lake Superior ports grew up with the development of the iron mines and the shipment of ore to the Lower Lakes. Similarly, the growth of Ashtabula, Conneaut, Cleveland, and other Lake Erie ports was stimulated by the transfer of ore from boat to rail on its way to the Pittsburgh region (Fig. 315), and by the return trade in coal coming from the nearby Ohio and Pennsylvania fields. Milwaukee and Chicago are great grain and flour shipping points, and the latter formerly had an immense lake trade in lumber (pp. 433, 437).

Chicago became the greatest lake port because of its superior geographic advantages. (1) It is near the head of Lake Michigan, which extends farther than the other lakes into the heart of the country. (2) It is located more centrally than its rivals with reference to the richer areas of glacial soil and the areas leading in the production of corn (Fig. 409), wheat (Fig. 410), swine (Fig. 426), and cattle (Fig. 424). (3) All land traffic from the Northwest to the eastern part of the country must pass around Lake Michigan, and is therefore tributary to Chicago. The latter is accessible also by land from the south and east, from which directions many railroads have been built to Chicago to meet the traffic of the West and Northwest. Because of its strategic position, Chicago is the greatest railroad center in the world (Fig. 440).

The importance of water transportation to the growth of the leading cities of the country is reflected in the fact that of the 28 cities having in 1910 a population of more than 200,000, 23 are situated on navigable waters. Of the 23, 10 are seaports, 7 are on the Mississippi System, and 5 are on the Great Lakes.

(4) All the important seaports, river ports, and lake ports of the United States are also more or less important as railroad centers. There are also a number of large cities without water transportation, like Columbus, Ohio, and Indianapolis, which now owe their commercial importance entirely to the fact that they are at the junction of several railroad lines. The greater cities of the United States had attained importance because of their natural advantages, before the appearance of railroads. Railroads were built to them to share in existing trade, which they later helped to increase. On the other hand, the extension of railroads throughout the country caused a multitude of small cities and villages to spring up on sites without natural advantages. Such places serve as collecting and distributing points for the surrounding country, and, if junctions, derive more or less benefit from the resulting exchange and transfer of traffic.

While the more important conditions which give rise to commercial centers have been mentioned, villages and cities may grow up at critical points on lines of communication not included in the foregoing classification. Thus a ford or ferry on a river may locate a town. Harrisburg, Pennsylvania, developed from Harris' Ferry, where a land route toward the west crossed the Susquehanna River; Zanesville, Lancaster, and Chillicothe, Ohio, grew up where an important early road (Zane's Trace) crossed the Muskingum, Hocking, and Scioto rivers. Again, a mountain pass upon which important trade routes focus may give rise to a city. Cumberland, Mary-

land, has grown up in front of Wills Creek Water-Gap, important since the colonial period (p. 359). The growth of Denver has been stimulated by its relation to several of the passes in the Rocky Mountains.

Manufacturing cities. Most large cities which are dominantly commercial centers are important also as manufacturing centers (p. 573), for their transportation facilities favor the assembling of raw materials and the marketing of manufactured products, and abundant labor is available. New York, the commercial metropolis of the country, leads also in manufacturing; Chicago, the leading inland commercial city, is the second industrial center; and Philadelphia, the fourth commercial center, is third in industry (Fig. 436). On the other hand, all industrial cities are necessarily, in varying degree, trade centers. In most cities, therefore, commercial and industrial activities are blended in varying proportions determined largely by geographic conditions. The factors which control the distribution of manufacturing industries (pp. 567-572), obviously control also the location of the cities to which those industries may give rise. Most distinctly industrial cities are located in response to (1) power resources, like many of the New England cities (p. 570), or (2) raw materials, like Birmingham, Alabama.

Mining cities. Many villages and cities, especially in the West, have developed from rude camps about mines. As the mining industry in a given locality grew, tents gave place to buildings of wood and brick, business and professional men appeared to supply the needs of the miners, and busy settlements resulted, which in many cases became cities in a few years. Scranton (Pennsylvania), Joplin (Missouri), Deadwood (South Dakota), Cripple Creek (Colorado), and Placerville (California) are types of a large number of cities and towns which have grown up solely because of the wealth of adjacent mines. Many cities of this class are in places where, without the mines, there probably never would have been cities (p. 499).

Many cities at which there are no mines depend largely on the mining industry. Thus Pueblo (Colorado) and Anaconda (Montana) were founded primarily for extracting metals from ores. Again, Sacramento and Denver first became important as outfitting and supply stations for nearby mines. Indeed, there are few cities in the West which have not been influenced by the mining industry.

The ruins of scores of abandoned mining towns are scattered throughout the leading mining states. They were built hurriedly in boom times, and deserted because of the failure of the mineral deposit, the discovery of richer deposits elsewhere, or for some other reason.

Political centers. Few cities are merely political centers, for even though founded as such, their growth is almost certain to attract commercial, if not industrial, enterprises. Washington, D. C., is a conspicuous exception. In locating state capitals, accessibility for the majority of the people has been a leading consideration. In states having a fairly uniform distribution of population and equal facilities for travel, the political center tends toward the geographic center. Thus the capital of Illinois shifted from Kaskaskia to Vandalia, and later to Springfield; that of Tennessee from Knoxville to Nashville; and that of Pennsylvania from Philadelphia to Harrisburg. The centrally located capitals of Ohio, Indiana, Iowa, Missouri, and South Dakota illustrate the same principle. On the other hand, where the mass of the population is in one section of the state little attention has been paid to the question of the geographical center. Thus Boston, Albany, Lincoln, and Topeka, though far from the geographic centers of their respective states, are not far from the centers of population in each case. The question of accessibility was considered, among others, in choosing the site for the national capital, but with the acquisition and settlement of the West it has come to have a marginal location.

Health and pleasure resorts. The leading cities of this type have been stimulated in their growth by geographic conditions which make them attractive to the tourist or beneficial to the invalid; most of them are ocean, mountain, or natural spring resorts. The attraction of the ocean resorts lies partly in their facilities for boating and bathing, but chiefly in the occurrence of the cool sea-breeze (p. 114) in the hot days of summer, and in the tempering effects of winds from the sea in winter. Newport and Atlantic City are typical.

Atlantic City, situated on one of the barrier reefs ("beaches") off the New Jersey coast, has a good beach with excellent bathing and a climate so tempered by the ocean that it is frequented by many visitors in winter as well as in summer. Fogs are rare, and malaria (so common in many parts of the state; p. 460) is almost unknown, owing to the extensive areas of pine forest and dry, sandy soil which lie inland from this part of the coast. Although the permanent population of Atlantic City is only 46,000, the transient summer population is more than a quarter of a million.

Asheville (North Carolina) and Colorado Springs are among the best-known mountain resorts (pp. 212, 482) of the United States, and Hot Springs, Arkansas, is the most prominent health resort created by "medicinal" springs (p. 329). Los Angeles and several neighboring places in southern California have become important resorts chiefly for climatic reasons.

Location of early cities. At one time the concentration of people in villages and cities was chiefly because of the necessity for defense. For this reason many old cities are located in places affording protection, as on hills and islands. Considerations of defense as well as of trade located many of the towns founded in this country during the colonial period.

The site of Boston was chosen because of (1) its strength for defense, (2) its harbor, and (3) a supply of good water. Boston peninsula was connected with the mainland by a narrow isthmus, so low that for years it was submerged at high tide if a strong wind blew off the bay. This favored defense toward the land. The harbor is roomy, deep, farther inland than any other north of Cape Cod, and is located centrally on the coast of Massachusetts. This favored trade, and helped to make Boston from the outset the leading town of the colony. New York was founded on Manhattan Island for safety and in the expectation that the Hudson River would, as it did, give it command of the trade of a large district. Quebec was founded to guard the St. Lawrence highway and to command the fur trade of the Interior. The river is much narrower there than at any point farther downstream (Why advantageous?); the inland location was expected to afford security from European enemies; and the "Heights of Quebec" furnished an ideal site for a fortress. Montreal was laid out on a hilly island in the St. Lawrence River, opposite the mouth of the Ottawa River. Thus it was reasonably safe from unexpected attack, and able to draw upon the trade of both valleys.

Questions

1. Discuss the leading occupations of the United States as factors affecting density of population.
2. Why are there more important cities in the United States on the Atlantic coast than on the Pacific coast?
3. Compare and contrast the commercial advantages of the seaports of southeastern and northeastern United States.
4. Why are there fewer cities on the Great Lakes in Canada than in the United States?
5. Give examples, not mentioned in the text, of American and foreign cities which have profited from their position (1) on rivers at the head of navigation, (2) at the junctions of important rivers.
6. Lexington was for years the largest community in Kentucky. Now the population of Louisville is more than six times that of Lexington. Explain the change.

7. Why has Chicago derived greater commercial advantages from its location near the head of Lake Michigan, than Duluth has from its position near the head of Lake Superior?

8. Explain the fact that $^7/_{10}$ of the cities in the United States having in 1910 a population of more than 100,000 are situated east of the Missouri River and north of the Ohio.

9. (1) Explain the relatively small population (1900) of (a) southern Florida and (b) northern Wisconsin and northern Michigan, as shown by Fig. 442.

(2) Explain the distribution of population in (a) Montana, (b) the belt through southeastern Idaho and Utah, and (c) New Mexico.

(3) Account for the areas of relatively dense and of relatively sparse population in California.

(4) Cite illustrations (not involved in preceding questions) from the map, showing the influence on the distribution of population of (a) topography, (b) means of communication, and (c) natural resources.

10. (1) Why is the railroad web (Fig. 440) thickest in the northeastern quarter of the country?

(2) Account for the thinness of the railroad net in northern New England, northern New York, and the northern Lake Region.

(3) Why is the dominant direction of railroads east-west in the Great Plains?

(4) Why the relatively small railroad mileage of the western half of the country?

(5) Explain the distribution of railroads in California.

(6) Interpret the dominant north-south direction of the railroads in the southern Interior.

(7) Explain the striking gap in the railroad net between the lower Missouri and lower Arkansas rivers.

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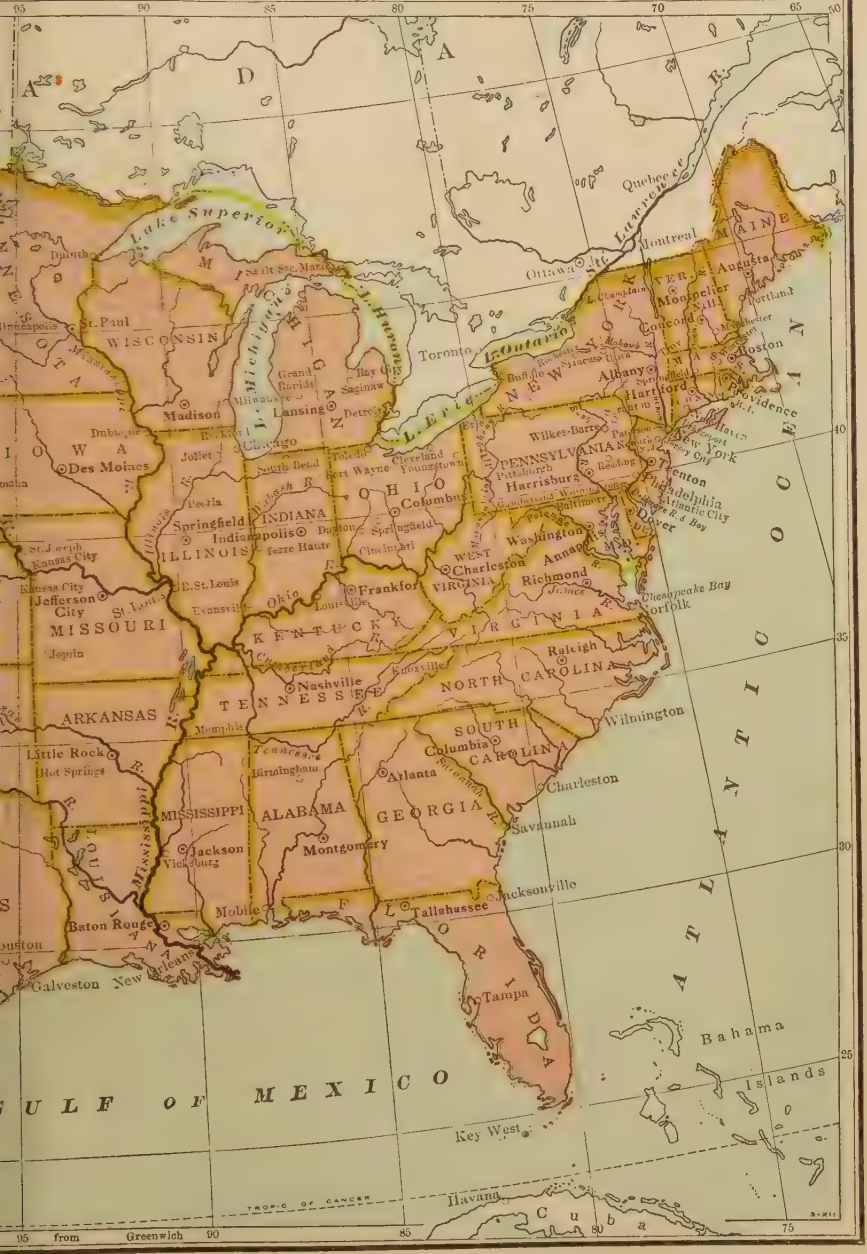
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
ASIA
GREENLAND
ALASKA
Hudson Bay
Baffin Bay
Davis Strait
Hudson Strait
Labrador Peninsula
Great Northern Plain
THE ROCKY MOUNTAINS
THE CASCADES
Bering Str.
Arctic Ocean
Melville Sd.
Lancaster Sd.
Barrow
Grant Land
Greenland
Iceland
Arctic Circle
Magnetic Pole
Banks Land
Pr. Albert Land
Victoria Land
Melville I.
N. Devon
Somerset I.
Pr. of Wales I.
Cumberland St.
Frobisher Bay
C. Farewell
Yukon R.
Ft. Yukon
Mt. McKinley
Mt. Wrangell
Mt. St. Elias
Mt. Fairweather
Alaska Pen.
Kodiak I.
1000 fathoms
100 fathoms
Dawson
Mackenzie R.
Great Bear L.
Great Fish or Back R.
Great Slave L.
Liard R.
Southampton I.
Port Churchill
Labrador
Nain
Newfoundland
C. Race
Sitka
Queen Charlotte Is.
Queen Charlotte Sd.
Vancouver I.
Juan de Fuca Str.
Mt. Columbia
Mt. Rainier
Mt. Baker
Columbia R.
Portland
Peace R.
Athabasca R.
Lake Athabasca
Little Slave Lake
Edmonton
Saskatchewan R.
Winnipeg
Lake Winnipeg
Lake Manitoba
Red R.
Nelson R.
Churchill
Reindeer L.
James Bay
Albany R.
Height of Land
Lake of the Woods
Nipigon
L. Superior
Duluth
Ottawa R.
Montreal
Quebec
St. Lawrence R.
Gulf of St. Lawrence
Cape Breton
Pen. of Nova Scotia
C. Sable
Laurentide Highlands
Anticosti
Saguenay R.
Lake St. John
Bell R.
Mississippi R.
St. Louis
Missouri R.
Yellowstone R.
Columbia R.
Fraser R.
Vancouver
Seattle
Portland
Minneapolis
St. Paul
Chicago
Detroit
Toronto
Buffalo
Rochester
Albany
Boston
New York
Philadelphia
Washington
Pittsburg
Cincinnati
St. Louis
Kansas City
Omaha
Denver
Salt Lake City
San Francisco
Los Angeles
San Diego
Portland
Seattle
Victoria
Vancouver
Winnipeg
Regina
Calgary
Edmonton
Prince Albert
Saskatoon
Moose Jaw
Medicine Hat
Brandon
Fort William
Port Arthur
Sault Ste. Marie
Kingston
Ottawa
Montreal
Quebec
Halifax
St. John
Charlottetown
Fredericton
Moncton
Sydney
Truro
Yarmouth
Digby
Annapolis
Windsor
Kentville
Wolfville
Amherst
Pictou
New Glasgow
Antigonish
Guysborough
Canso
Port Hawkesbury
Baddeck
Sydney Mines
North Sydney
Glace Bay
New Waterford
Dominion
Reserve Mines
Louisbourg
Arichat
Mulgrave
Port Hastings
Inverness
Port Hood
Mabou
Judique
Broad Cove
Margaree Harbour
Cheticamp
Meat Cove
Cape North
Cape Breton
Cape Ray
Port aux Basques
Channel
Burgeo
Ramea
Grand Bruit
Rose Blanche
Harbour Le Cou
Lourdes
Fortune
St. Pierre
Miquelon
Langlade
Grand Miquelon
Petite Miquelon
Placentia
Placentia Bay
Argentia
Harbour Grace
Carbonear
Bay de Verde
Trinity
Bonavista
Bonavista Bay
Clarenville
Port Rexton
Catalina
Greenspond
Twillingate
Fogo
Change Islands
Notre Dame Bay
Lewisporte
Gander
Gander Bay
Gander Lake
Terra Nova
Glovertown
Eastport
Musgrave Harbour
Clarke's Beach
Port de Grave
Brigus
Cupids
Conception Bay
Conception Harbour
Harbour Main
Holyrood
Torbay
Petty Harbour
Bay Bulls
Witless Bay
Ferryland
Aquaforte
Calvert
Cape Race
St. John's
Signal Hill
Kelligrews
Topsail
Portugal Cove
Pouch Cove
Flatrock
Torbay
Logy Bay
Middle Cove
Outer Cove
Bauline
Pippy Park
Mount Pearl
Paradise
Goulds
Petty Harbour
Bay Bulls
Witless Bay
Ferryland
Aquaforte
Calvert
Cape Race
St. John's
Signal Hill
Kelligrews
Topsail
Portugal Cove
Pouch Cove
Flatrock
Torbay
Logy Bay
Middle Cove
Outer Cove
Bauline
Pippy Park
Mount Pearl
Paradise
Goulds

PHYSICAL

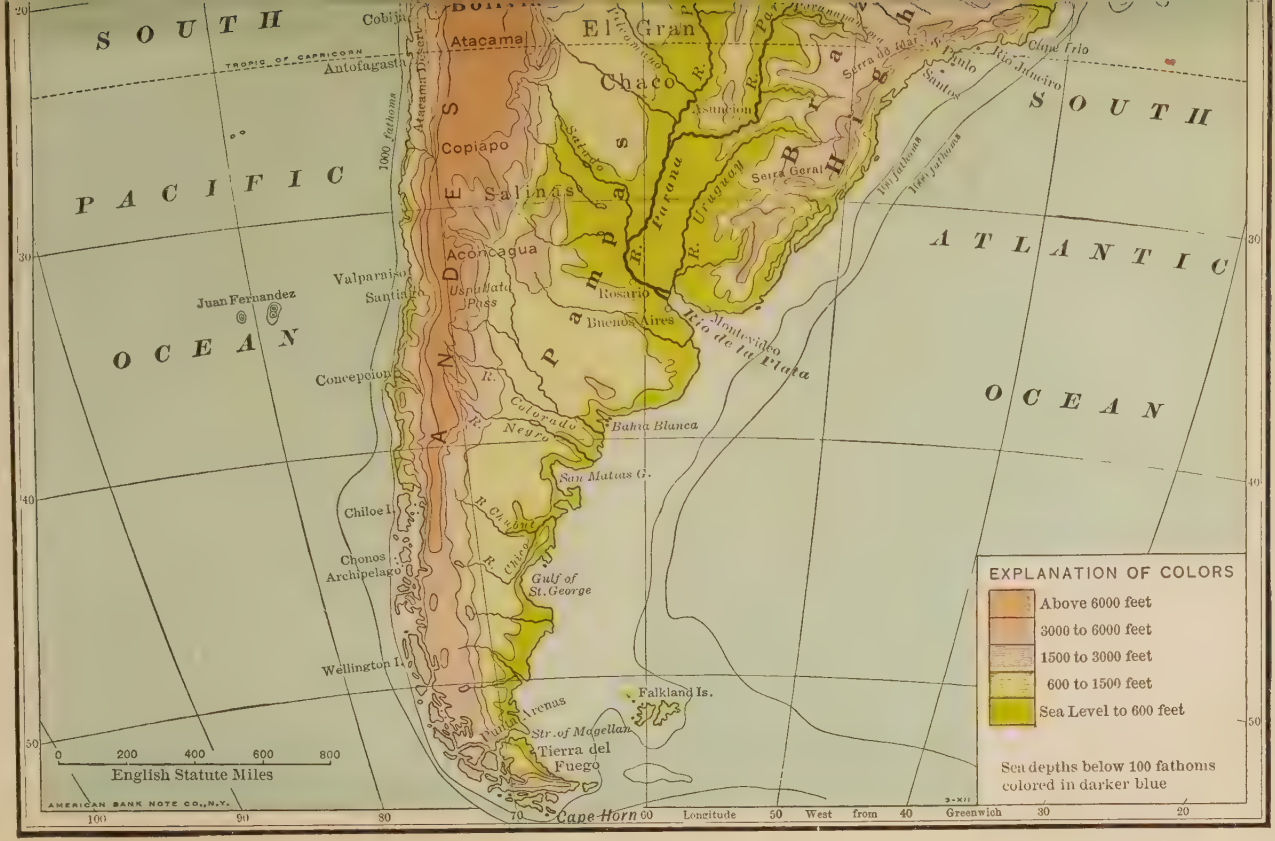
MAP OF NORTH AMERICA.

PLATE I.

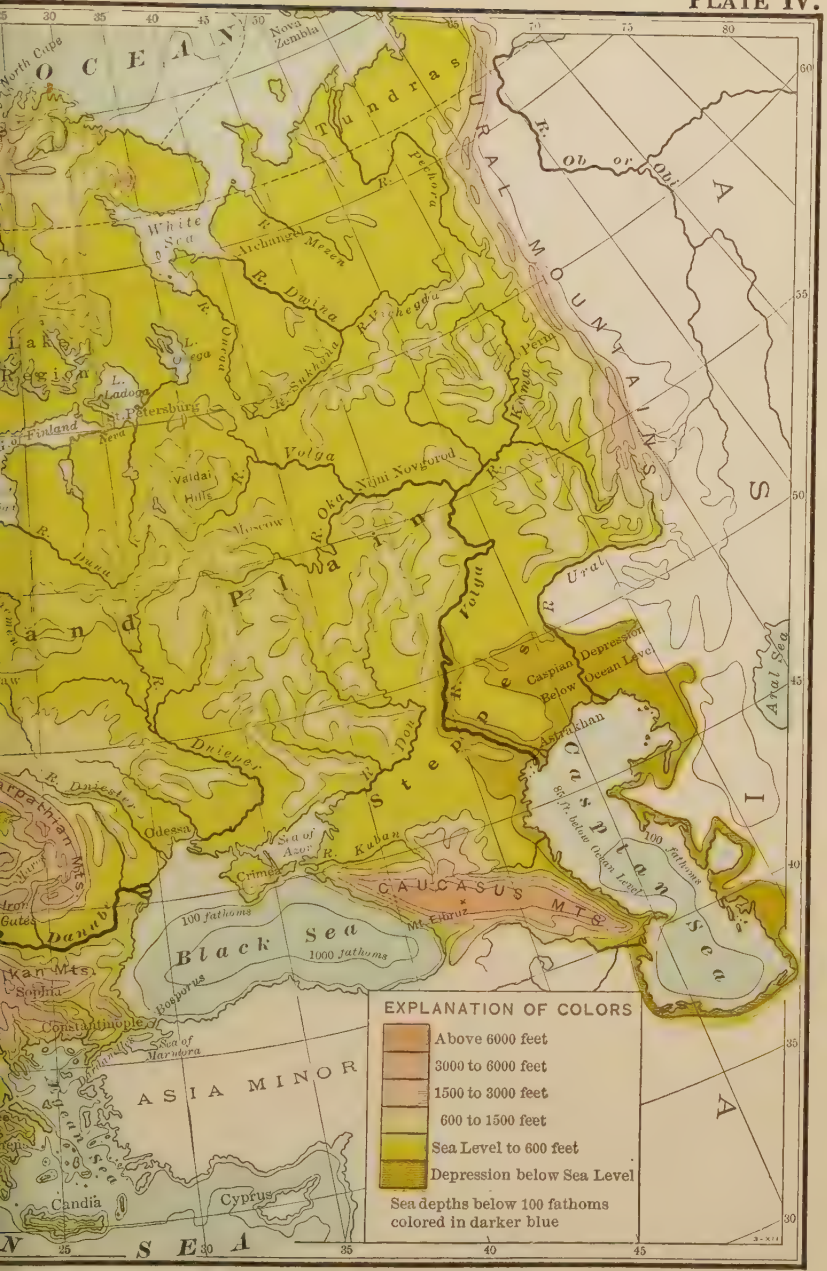
Vanconver
Puget Sound
Seattle
WASHINGTON
Olympia
Tacoma
Columbia R.
Spokane
Missouri R.
MONTANA
Helena
Butte
NORTH DAKOTA
Bismarck
Portland
Salem
Willamette R.
Snake R.
OREGON
Yellowstone R.
Boise City
IDAHO
SOUTH DAKOTA
Pierre
WYOMING
Eureka
Green R.
Great Salt Lake
Salt Lake City
Cheyenne
NEBRASKA
Platte R.
Sacramento R.
Carson City
NEVADA
UTAH
Green R.
Leadville
Denver
COLORADO
Cripple Creek
Colorado Spgs.
Pueblo
KANSAS
Oakland
San Francisco
San Joaquin R.
Los Angeles
Santa Fe
Canadian R.
OKLAHOMA
Oklahoma C
ARIZONA
NEW MEXICO
Colorado R.
San Diego
Phœnix
Gila R.
Pecos R.
Fort W
El Paso
TEXAS
San A
Rio Grande
MEXICO
PACIFIC OCEAN
State Capitals
0 100 200 300 400 500
English Statute Miles
AMER CAN BANK NOTE CO. N.Y.
125 120 115 110 105 100
50 45 40 35 30 25
Longitu


Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
St. Lawrence R.
Quebec
Montreal
Ottawa
Toronto
Detroit
Chicago
Milwaukee
Minneapolis
St. Paul
Duluth
WISCONSIN
MICHIGAN
MINNESOTA
IOWA
Des Moines
Dubuque
Madison
Lansing
Grand Rapids
Saginaw
Bay City
Buffalo
Rochester
Syracuse
Albany
Hartford
Boston
Providence
Portland
Augusta
Concord
Montpelier
MAINE
VERMONT
NEW YORK
MASSACHUSETTS
Wilkes-Barre
Trenton
Philadelphia
Atlantic City
Delaware R. & Bay
Dover
Harrisburg
PENNSYLVANIA
Pittsburgh
Reading
Cleveland
Youngstown
Toledo
Fort Wayne
South Bend
OHIO
Columbus
Springfield
Dayton
Cincinnati
Indianapolis
INDIANA
Terre Haute
Peoria
Joliet
ILLINOIS
Springfield
St. Louis
East St. Louis
Kansas City
Jefferson City
MISSOURI
Joplin
Evansville
Louisville
Frankfort
KENTUCKY
Nashville
TENNESSEE
Memphis
ARKANSAS
Little Rock
Hot Springs
Washington
Annapolis
Baltimore
Potomac R.
Chesapeake Bay
Norfolk
Richmond
Charleston
WEST VIRGINIA
VIRGINIA
Raleigh
NORTH CAROLINA
Wilmington
Knoxville
Columbia
SOUTH CAROLINA
Charleston
Atlanta
Savannah
Birmingham
Tennessee R.
Chattanooga
MISSISSIPPI
ALABAMA
GEORGIA
Montgomery
Jackson
Vicksburg
Mobile
Tallahassee
Jacksonville
Baton Rouge
New Orleans
Galveston
FLORIDA
Tampa
Key West
Bahama Islands
Havana
Cuba
GULF OF MEXICO
ATLANTIC OCEAN
TROPIC OF CANCER
95
90
85
80
75
70
65
60
40
35
30
25
from Greenwich

PHYSICAL MAP


SOUTH
PACIFIC
OCEAN
ATLANTIC
OCEAN
TROPIC OF CAPRICORN
Cobija
Atacama
Antofagasta
Atacama Desert
1000 fathoms
ANDES
Copiapo
Salinas
Aconcagua
Valparaiso
Santiago
Juan Fernandez
Uspallata Pass
Concepcion
Chiloe I.
Chonos Archipelago
Wellington I.
Gulf of St. George
Rosario
Buenos Aires
Rio de la Plata
Montevideo
Bahia Blanca
San Matias G.
R. Colorado
R. Negro
R. Chubut
R. Chico
Punta Arenas
Str. of Magellan
Falkland Is.
Tierra del Fuego
Cape Horn
El Gran Chaco
Asuncion
R. Paraguay
R. Parana
R. Uruguay
Pampas
Sierra de Mar
Sierra Geral
Serra da Mantiqueira
S. Paulo
Santos
Rio Janeiro
Cape Frio
100 fathoms
1000 fathoms
1000 fathoms
0 200 400 600 800
English Statute Miles
AMERICAN BANK NOTE CO., N.Y.
EXPLANATION OF COLORS
Above 6000 feet
3000 to 6000 feet
1500 to 3000 feet
600 to 1500 feet
Sea Level to 600 feet
Sea depths below 100 fathoms colored in darker blue
3-XII
100 90 80 70 60 Longitude 50 West from 40 Greenwich 30 20
20 30 40 50

ARCTIC
Iceland
Red Kjeruk
1000 fathoms
Limit of Drift Ice
ARCTIC CIRCLE
Lofoten Is.
Trondhjem Fiord
Faroe Is.
Shetland Is.
Soune Fd.
Hebrides
Orkney Is.
Moray Firth
BRITISH ISLES
Edinburgh
North Sea
Dogger Bank
Helgoland
Skager Rack
Christiania
Stockholm
Dublin
Valencia I.
C. Clear
Irish Sea
Liverpool
St George's Chan.
Lands End
100 fathoms
English Channel
London
Amsterdam
Rotterdam
Hamburg
Berlin
Harz Mts.
Cologne
Brussels
Paris
Bay of Biscay
1000 fathoms
C. Finisterre
R. Minho
Cantabrian Mts.
Bordeaux
Pyrenees
Spanish Plateau
Lisbon
R. Tagus
Madrid
Sa. Guadarrama
C. St. Vincent
Guadiana R.
Sierra Morena
Str. of Gibraltar
Sierra Nevada
Marseille
Gulf of Genoa
Corsica
Elba
Rome
Naples
Mt. Vesuvius
Sardinia
Balearic Isles
MEDITERRANEAN
1000 fathoms
Sicily
Mt. Etna
AFRICA
ATLANTIC OCEAN
0 100 200 300 400 500
English Statute Miles
AMERICAN BANK NOTE CO., N.Y.
5 Long. West 0 Longitude 5 East from 10 Greenwich 15


EXPLANATION OF COLORS
Above 6000 feet
3000 to 6000 feet
1500 to 3000 feet
600 to 1500 feet
Sea Level to 600 feet
Depression below Sea Level
Sea depths below 100 fathoms colored in darker blue
Black Sea
1000 fathoms
100 fathoms
Caspian Sea
Caspian Depression Below Ocean Level
85 Ft. below Ocean Level
CAUCASUS MTS.
Mt. Elbruz
ASIA MINOR
Steppes
Tundras
URAL MOUNTAINS
Ural
R. Ob or Oui
R. Petchora
White Sea
R. Archangel
R. Dwina
R. Onega
L. Onega
L. Ladoga
St. Petersburg
Gulf of Finland
R. Sukhona
R. Kama
Perm
R. Volga
Valdai Hills
Nijni Novgorod
R. Oka
Moscow
R. Don
Volga
Caspian Depression Ocean Level
Astrachan
Aral Sea
R. Dnieper
R. Dniester
Odessa
Sea of Azof
Crimea
R. Kuban
Carpathian Mts.
Danube
Balkan Mts.
Sophia
Bosporus
Constantinople
Sea of Marmora
Dardanelles
Candia
Cyprus
North Cape
Nova Zembla
OCEAN
SEA
Plain
Russian
Arctic
Asiatic

ARCTIC O
Nova Zembla
Kara Sea
Arctic Circle
100 fathoms
North Sea
White Sea
Great Baltic Lowland Plain
Baltic Sea
R. Dwina
R. Obi
R. Tobol
Tobolsk
R. Volga
R. Ural
R. Donetz
R. Danube
R. Don
Constantinople
Dardanelles
Black Sea
Caspian Depression (below Sea Level)
Astrakan
Caucasus Mts.
Mt. Elburz
Batum
Kirghiz Steppes
Aral Sea
Syr Darya
Khiva
Amu Darya
Tableland of Asia Minor
Kurus Mts.
Armenian Highlands
Euphrates R.
Mesopotamian Plains
Mediterranean Sea
Cyprus
Alexandria
Cairo
Isthmus of Suez
Lebanon Mts.
Dead Sea
Syrian Desert
Nile R.
Nefud Desert
Red Sea
Plateau of Iran
Persian Gulf
Zagros Mts.
Salt Desert
Herat
Hindu Kush
Khaibar Pass
Pamirs
Karakoram Mts.
Indus R.
Bolan Pass
Sulaiman Mts.
Nejd Tableland of Arabia
Mecca
Strait of Ormuz
G. of Oman
Delhi
Indus Plain
Vindhya Mts.
Gulf of Cambay
Bombay
Deccan
Western Ghats
Eastern Ghats
Arabian Sea
Gulf of Aden
Strait of Bab el Mandeb
Aden
Socotra I.
INDIAN O
C. Comorin
EXPLANATION OF COLORS
Above 6000 feet
3000 to 6000 feet
1500 to 3000 feet
600 to 1500 feet
Sea Level to 600 feet
Depression below Sea Level
Sea depths below 100 fathoms colored in darker blue
0 200 400 600
English Statute Miles
AMERICAN BANK NOTE CO., N.Y.
Longitude - East from

Bering Strait
Gulf of Anadir
Delta of the Lena
Siberian Plain
Bering Sea
Kamchatka Pen.
Stanovoi Mts.
Okhotsk
100 fathoms
Sea of Okhotsk
Sakhalin Island
Kurile Islands
Yakutsk
Verkhoyansk Mts.
Yablonoi Mts.
Lake Baikal
Irkutsk
Khingan Mts.
Vladivostok
Sea of Japan
Honshu
Fujiyama
Tokio
Yokohama
Mongolian Plateau
Gobi
Peking
Gulf of Pechili
Great Plain of China
Yellow Sea
Korea Strait
Shikoku
Kiushiu
Nan Shan
Hoang Ho
Shanghai
East China Sea
Tsining Mts.
Yunling Mts.
Tropic of Cancer
Tibet
Lhasa
Kanchanjanga Mts.
Formosa
Formosa Str.
Nanling Mts.
Canton
Hongkong
Luzon I.
PHILIPPINE ISLANDS
Hainan
Gulf of Tonkin
Indo China Peninsula
Mindoro
Samur
Mindanao I.
Palawan
Sulu Sea
Sulu Archipelago
Celebes Sea
EQUATOR
Moluccas Is.
Gulf of Siam
C. Cambodia
Malay Pen.
Singapore
Sumatra
BORNEO
Java
Timor
Arafura Sea
PACIFIC OCEAN
110
120
130
140
150
160
70
60
50
40
30
20
10
0
90
100
110
130

EUROPE
ASIA
ARABIA
Bay of Biscay
C. Finisterre
SPAIN
Balearic Is.
Corsica
Sardinia
ITALY
Adriatic Sea
R. Danube
TURKEY
Black Sea
100 fath.
Caspian Sea
Aral Sea
MEDITERRANEAN SEA
1000 fath.
Sicily
GREECE
Crete
Cyprus
C. St. Vincent
Strait of Gibraltar
Ceuta
Tunis
Algiers
Madeira Is.
1000 fathoms
Morocco
Atlas Mts.
Algerian Plateau
G. of Sidra
Gulf of Cabes
Tripoli
Barka Plateau
Delta of the Nile
Suez Canal
Wargla
Algerian Sahara
El Erg
Oasis of Ghadames
Oasis of Aujila
Alexandria
Isthmus of Suez
Suez
Canary Is.
Wady Draa
Oasis of Guraia
Oasis of Tuat
C. Bojador
Tasili Plateau
Oasis of Fezzan
Oases of Ghat
Oases of Kufra
Oases of Siwa
Oasis
Cairo
G. of Akaba
Persian Gulf
Libyan Desert
Sahara or Great Desert
Anaggar Pl.
El Juf
1st Cataract
TROPIC OF CANCER
Nubian Desert
2nd Cat.
3rd Cat.
4th Cat.
5th Cat.
Dongola
Snakim
Berber
Tibesti
Tarso Mts.
Borku
Adghagh Plateau
Air or Asben
Oasis of Kawar
Timbuktu
R. Senegal
St. Louis
C. Verde
R. Gambia
Hombori Mts.
Joliba
Bani R.
Niger R.
Kano
Chaba
L. Tchad
Bahr el Ghazal
El Fasher
El Obeid
Khartum
Blue Nile
White Nile
R. Atbara
Plateau of Abyssinia
Tsana
Strait of Bab-el-Mandeb
Gulf of Aden
Socotra
Cape Guardafui
Berbera
Nogal
Mt. Loma
Mt. Daro
Yakoba
Mt. Alantika
R. Benue
R. Shari
Bahr el Arab
Bahr el Ghazal
Sobat R.
Mt. Vergi
SUDAN
Freetown
10
20
30
40
50
60

PHYSICAL MAP OF AFRICA.

PLATE VI.

313-320